INSIDE! Pull-out star chart

EXCLUSIVE: Handbook of meteorites

How to start a space-rock collection p. 70

August 2006

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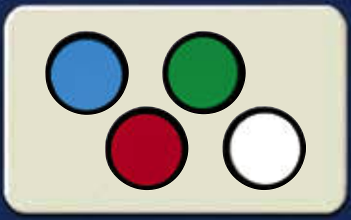

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RON MILLER FOR *ASTRONOMY*

ON THE COVER

Earth receives a constant bombardment of objects. Meteors — bright streaks of light in the sky — sometimes survive their fiery passage and land on Earth as meteorites. This special issue examines where meteorites come from, what they're made of, and how they affect our planet.

VOL. 34, NO. 8

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Observing, telescopes, origin and fate of the cosmos

august 2006

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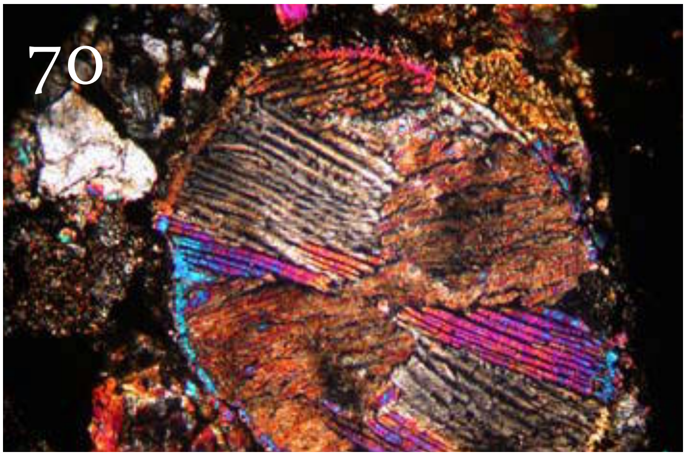
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BY DAVID J. EICHER

The meteorites special issue

November 7, 1492, a short time after Christopher Columbus arrived in the New World, a huge explosion rocked the upper Rhineland of France, and stone rained onto the fields of Ensisheim.

ASTRONOMY: MICHAEL E. BAKICH

EDITOR David J. Eicher holds the Zagami meteorite — the largest chunk of Mars on Earth.

A boy who witnessed the rock's descent took city officials to the fall site, and the meteorite, while not the first discovered in history, transformed science. It forced people to believe that stones fall out of the sky.

Five hundred years later, we know meteorites bring us samples of asteroids, and a few give us pieces of the Moon and Mars. They provide planetary scientists insight into the solar system, and they remind us we live in a dynamic space environment.

The issue you hold is the first-ever special issue devoted to the subject of meteorites. It all starts with the University of Arizona's David Kring, a meteorite expert, who describes the latest thinking on the science of meteorites ("Unlocking the solar system's past," page 32) and details the fascinating cultural story of Earth's most famous impact crater, Arizona's Meteor Crater ("Blast from the past," page 46).

The story continues with Mike Reynolds, professor of astronomy at Florida Community College and author of the book *Falling Stars*. In "Earth under fire" (page 40), Reynolds surveys the remnants of impact craters on our planet's surface and what they tell us about past collisions.

Then, Bill Cooke of NASA's Marshall Space Flight Center gives us "The great interplanetary rock swap" (page 64), which describes how the rarest meteorites come from the Moon and Mars. It's an engrossing tale of how the inner planets and moons exchanged debris following ancient impacts.

Nothing compares to holding a space rock in your own hands, and many people have taken up collecting them. In "How to start your meteorite collection" (page 70), O. Richard Norton provides an overview of the field and what to concentrate on.

Appearing throughout this issue are four articles showcasing the major types of meteorites and their basic classifications. Assembled by Senior Editor Michael Bakich, the articles highlight more than 60 well-known specimens. The photos come from the spectacular collection of Robert Haag, a Tucson-based meteorite collector and dealer. *Astronomy* Contributing Editor Raymond Shubinski profiles Haag's amazing story in "Rock star" (page 84).

When Bakich, Shubinski, and I visited Tucson in February for the annual Tucson Gem and Mineral Show, we had the privilege of talking with Haag at his house and holding the Zagami main mass, the largest chunk of the planet Mars on Earth. It was an electrifying experience.

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Astronomy is giving away 100 Campo del Cielo meteorites, fragments from an iron that fell in Argentina some 4,000 to 6,000 years ago. The Campo pieces consist of 92-percent iron, 7-percent nickel, and trace metals. For a chance to win, simply go to www.astronomy.com/meteorite (see the ad on page 14). Good luck!

Yours truly,

David J. Eicher
Editor

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Volume 34, Number 8

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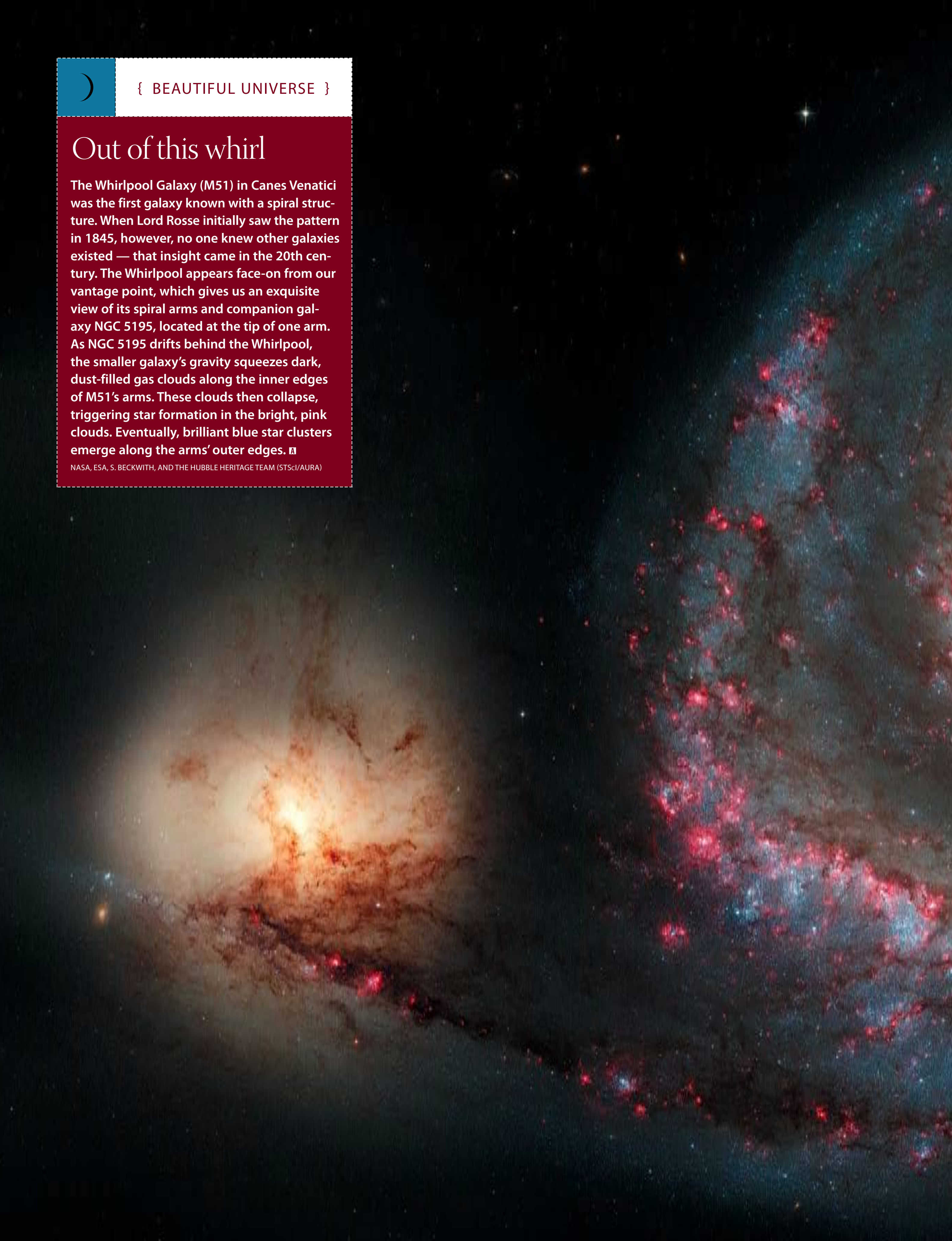

The Whirlpool Galaxy (M51) in Canes Venatici was the first galaxy known with a spiral structure. When Lord Rosse initially saw the pattern in 1845, however, no one knew other galaxies existed — that insight came in the 20th century. The Whirlpool appears face-on from our vantage point, which gives us an exquisite view of its spiral arms and companion galaxy NGC 5195, located at the tip of one arm. As NGC 5195 drifts behind the Whirlpool, the smaller galaxy's gravity squeezes dark, dust-filled gas clouds along the inner edges of M51's arms. These clouds then collapse, triggering star formation in the bright, pink clouds. Eventually, brilliant blue star clusters emerge along the arms' outer edges.

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R200SS 8" f/4 Richfield Newtonian

Advanced Imaging & Visual

At f/4 there's no room for error when forming the surface of a parabolic mirror. Vixen's solution is to execute each R200SS mirror with its High-Precision Poly-Order Aspherical Mirror Molding Technique. The result: exquisite state-of-the-art paraboloid form. Compact 28" length and only 11.7-lbs, the large 60mm drawtube allows for a whopping 2.6° x 1.7° field-of-view on 35mm format. The perfect imaging mate for the GP-D2 equatorial mount.

Recommended Accessories

Coma Corrector

Eliminates coma in full-frame imaging. Can be left on for visual use.

LV Eyepieces

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(32x)
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Our famous Lanthanum eyepieces are fully multi-coated with huge 20mm eye-relief for comfortable observation and easy eyepiece projection planetary imaging.

SPHINX Equatorial Mount

"Vixen's newest go-to mount is a winner." — Astronomy

SPHINX mount with its Internet upgradable STAR BOOK controller, is the culmination of a decade of design experience. SPHINX responds nimbly and precisely to your commands due to its lightweight design with low-rotational momentum. STAR BOOK is striking with its 4.7" LCD screen and powerful CPU that produces localized star charts with Constellations, "goto" menus for 22,725 celestial objects: Messier, NGC/IC, Solar System, stars, and more. Auto-guider port works with SBIG guiders. Mount is controllable through popular planetarium programs such as *TheSky6* (*Serious* or *Pro*) and *Starry Nights* (*Pro* or *Pro Plus*).

The Reviews are In: "A telescope mount for the 21st century"

Astronomy magazine, November 2005

- ◆ "The Star Book is so easy to operate it flirts with user-interface perfection ... ."
- ◆ "As it stands now, the Sphinx is by far the easiest-to-use go-to mount."
- ◆ "Those interested in imaging should give this mount consideration."
- ◆ "The Sphinx is an extraordinary value because this amount of periodic error is normally encountered only in mounts 4 or 5 times its cost."
- ◆ "More good news: The mount is terrific."
- ◆ "To its credit, the screen worked well even at low temperatures — I subjected it to a test at -15° Fahrenheit (-26° Celsius) one night... ."

Recommended Accessories

Polar Axis Scope

6x20mm
for both hemispheres

Aluminum Case

Holds SPHINX, STAR BOOK, weights, battery case and more.

Tripod Carry Bag

Includes half-pillar pouch.

PORTA Alt-Az Mount

PORTA: Exceptionally Portable Mount!

Newly designed friction system for quickly pointing toward the object and hand tracking it with the 360° slow-motion controls. No fumbling with clutches or sectional slow-motion controls! Leave the counter-weights with the equatorials: simply balance scopes up to 9-lbs. on the altitude axis and start viewing! Standard Vixen dovetail mounting slot with lock and safety screw is fully SPHINX/GP-compatible. PORTA mount features interchangeable slow-motion knobs, tension adjustment and disassembly tools, built-in tool storage bay, tripod tray and aluminum legs.

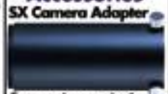
ED80Sf 80mm f/7.5 APO Refractor

Portable Affordable APO

Breakthrough price on an ED80Sf scope package including giant 9x50mm finder, dual T-thread flip-mirror with 1¼" eyepiece adapters, rotatable 2" eyepiece adapter with locking collar, Crayford focuser with tension/lock adjustment, tube rings with dovetail plate and telescope/accessory travel case! Included standard accessories make the ED80Sf the value leader in affordable 80mm APO scopes. Perfect size for PORTA mount makes this an exceptionally portable system.

Recommended Accessories

SX Camera Adapter



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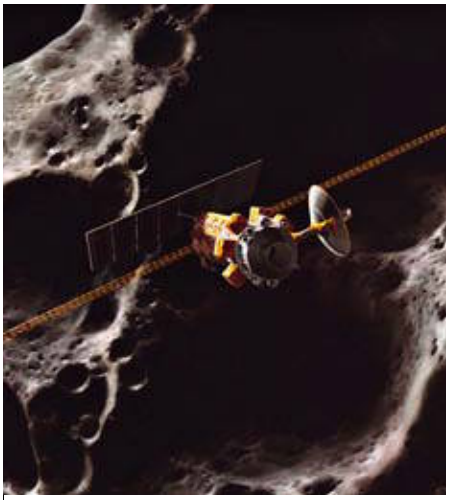
Earth marks the spot

Thank you for the excellent article on Apophis, "Fatal attraction" (May 2006). Bill Cooke did a masterful job stating the facts of this asteroid's close approach in 2029. Despite the slim odds of an Earth-impact, Apophis provides us an opportunity to test monitoring and response procedures for earthbound space debris. Amateur astronomers around the world should expect to help out when the time comes. Apophis can train us how to respond to astronomical emergencies.
— **DONALD CRAIG, JR.,** INDIANAPOLIS



NASA/JPL ILLUSTRATION

A SPACE MISSION to Apophis may be in our future. Astronomers plan to learn as much as they can about this asteroid to be prepared for any future, possibly fatal, close encounters of the rocky kind.

Star hype

I enjoyed the "Secret lives of stars" bonus foldout poster accompanying the April 2006 issue. On the poster, you list Aldebaran and Arcturus as examples of K-class (orange) stars, while you list Antares and Betelgeuse as M-class (red) stars. None of those is a main sequence star. Because your table lists the mass, radius, and lifetime of main sequence stars, shouldn't one serve as your example — like 61 Cygni for a K-class star and Proxima Centauri for an M class?
— **BRUCE McCLURE,** NORWOOD, NEW YORK

You raise a good point, one that we thought about long and hard. We opted to mention bright examples of each stellar class because there just aren't many well-known stars on the main sequence for all spectral types. Stars like 61 Cygni could certainly have been included instead, but we thought giving familiar examples — and ones in which the colors we included are discernible to the naked eye, at least through binoculars — made more sense. That's why we also listed the main sequence masses and radii, to show that those columns were of a different type than the other columns. — **RICHARD TALCOTT,** SENIOR EDITOR

100
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Give peace a chance

Yes, it's true. Unbelievably violent things go on in the universe and, unfortunately, right here on Earth. I wonder if *Astronomy* isn't getting a bit carried away by all this brutality. Each of your recent covers and cover stories seems to be more lurid than the last. It reminds me of one of those zany sci-fi pulp magazines showing some many-tentacled intergalactic creature swallowing up a space station. But the lure of astronomy for most of us is the cool, quiet beauty of the night sky. How about giving peace a chance?
— **DAVE BORENSTEIN,** RED BANK, NEW JERSEY

Corrections

In the caption on page 93 of the June 2006 issue ("Vixen's go-anywhere scope"), "triplet" should read "doublet." Also, the current combined street price of the Vixen ED80Sf and mount package is $975.

The diameters given for Pluto and Charon in "Pluto's new worlds" (June 2006) should be 1,454 miles and 752 miles, respectively. For a revised version of the diagram on page 47, visit the June 2006 online extras on Astronomy.com. — ***ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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BY BOB BERMAN

Magnetic attraction

When we think of cosmic power, magnetism doesn't usually come to mind. The Sun's nuclear furnace churns out blistering heat and blinding light, but magnetism plays no role in the fusion process, which converts our star's mass to energy. So a star's magnetic field is like cole slaw: nice but unnecessary. Certainly irrelevant in the energy big leagues. At least, that's how it always seemed.

Not anymore. During the past few years, researchers have learned that neutron stars — already among the universe's all-time strangest objects — can be wrapped in magnetic fields brawny enough to affect the rest of the cosmos.

The first hint of magnetic trouble came March 5, 1979, when a burst of gamma rays swept through the solar system at light-speed. Radiation monitors aboard spacecraft near Venus and Earth suddenly went off the scale.

The deadly torrent lasted for only ⅕ of a second, but in that eye blink, some mysterious object had given off twice the energy the Sun has emitted since the pyramids were built. The burst could not be explained by any known phenomenon. Eventually, the culprit was narrowed down to an invisible — to us — neutron star in a neighbor galaxy.

All that power from a tiny neutron star, a dead ex-sun that doesn't even boast a nuclear generator? Maybe we needed to take another look at these objects.

Neutron stars are tiny — 20 would easily fit within Yellowstone Park. They're the only stars with a solid surface.

A neutron star forms when a massive star collapses and sends supernova brilliance outward and a tiny remnant core imploding inward. That core — now a 12-mile-wide (19 kilometers) sun — spins crazily, often hundreds of times a second. Such frenzied motion causes its magnetic field to wrap around itself, intensifying the field lines. What's new about all of this is that for a brief period in a neutron star's youth, the magnetic field can reach a thousand-trillion gauss. By comparison, Earth's field is less than 1 gauss. With fields a million-billion times greater than a refrigerator magnet's, such stars are aptly called magnetars.

More bursts have arrived since that first eye-opener, and altogether a dozen magnetars have now been discovered. Only one, 18,000 light-years away in Cassiopeia, can be seen visually through telescopes. The others are detected solely by the radiation they emit. But more than a million other magnetars are thought to loiter unseen in the dusty hallways of the Milky Way.

MAGNETARS EMBODY the physics of extremes. Extremes of density, gravity, and magnetism.

I spoke with Vicky Kaspi of McGill University, who won the 2004 Herzberg Medal for her studies of these fantastic objects. She's obsessed with them.

"Magnetars are the only deep-space objects to directly affect Earth," she said.

"The [December 27] 2004 burst changed our ionosphere from night to day, and caused a significant drop in ham radio signals. Some fishermen in the arctic saw a sudden aurora at that moment."

And get this: Magnetars are powered not by nuclear energy like the Sun, nor by the loss of kinetic energy from rotation slowing, which is what lights up pulsars.

"In a magnetar, we see a unique source of power: All of its energy comes from the gradual loss of its magnetic field," Kaspi explains. The intense magnetism bends and deforms a magnetar's solid crust to produce starquakes. They are nothing like the tremors we get here, that can merely destroy a city. No, a neutron star's ultradense starquakes release titanic bursts of energy that actually create electrons and positrons — a form of antimatter. When these particles combine, they annihilate each other, and produce the lethal gamma rays that sweep through the universe.

Meanwhile, the magnetism slows the star. In a mere 10,000 years, according to current thinking, the magnetic field will weaken to a paltry 2 trillion times greater than Earth's. Then, the starquakes stop, the gamma rays die out, and the star may settle down to be a garden-variety neutron star.

In short, magnetars embody the physics of extremes. Extremes of density, gravity, and magnetism. No wonder they're so much fun to talk about.

As long as we keep our distance.

Imagine a future astronaut approaching a magnetar. At the Moon's distance from Earth (238,000 miles [383,000 km]), the magnetar would appear as a shapeless point. At half that distance, all the astronaut's credit cards get mysteriously erased.

He's now broke, but curiosity drives him forward. At 20,000 miles (32,000 km), the magnetar is still just a dot, but its magnetism now pulls every atom in the astronaut's body into long, strange, needle formations. By then it's too late, as he learns that these bizarre objects can truly hold a fatal attraction.

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BY GLENN CHAPLE

Bust out the big boy

"#$@&!" my brother-in-law gasped as he peered into the eyepiece of my 13-inch reflector. Michael is a gentle soul, not prone to blurt out profanities — even mild ones. In this instance, I couldn't blame him. He was reacting to his first-ever view of the magnificent globular cluster **M13** (NGC 6205) in Hercules. As the name implies, a globular star cluster is a spherical aggregation of stars — not hundreds, as is the case with open clusters like the Pleiades, but thousands upon thousands. If the lights of a small village represented an open cluster, a globular cluster would be the cosmic equivalent of London or New York City.

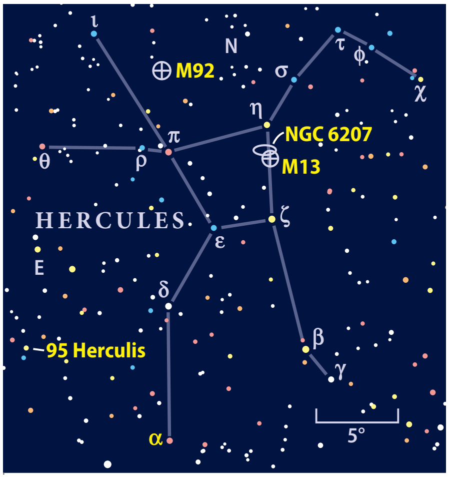
The telescopic appearance of a typical globular cluster has been likened to a spoonful of sparkling sugar dropped on a sheet of black velvet. Such is the incredible sight that greeted Michael's eyes.

Last month, Phil Harrington featured M13 in his binocular column ("It's Superman!"). As he noted, M13 is easily found between the stars Eta (η) and Zeta (ζ) Herculis in the "Keystone" of Hercules.

If you're lucky enough to live in a dark-sky area, you should be able to see M13 with the unaided eye (it shines at magnitude 5.8). Binoculars reveal a small circular patch of light, about ¼° wide — half the apparent diameter of the Full Moon.

While I'm a big fan of small-aperture telescopes, I reluctantly acknowledge their shortcomings where globular clusters are concerned. Small scopes do little to enhance M13's binocular appearance, merely enlarging the fuzzy ball. With a 3- or 4-inch scope and high magnification, you might be able to resolve the outer parts of M13. But to appreciate M13 or its kindred globulars in all their glory, you'll need at least a 6-inch telescope.

Because I wanted those spectacular big-scope views of globular clusters, I purchased a 13.1-inch Dobsonian-mounted reflector in 1980. This is the telescope through which Michael viewed M13, and it's the one I still use today whenever I want to get my M13 "fix."



WHILE SMALL SCOPES can lead you to Hercules' trove of visual delights, a 6-inch or larger scope lets you appreciate them on a new level. *ASTRONOMY*: ROEN KELLY

If you've never seen this cosmic masterpiece with a large-aperture telescope, you're in for an eye-popping treat. Just be forewarned: When you peer into the eyepiece, be sure there are no children around!

Most observers are so captivated by M13's dramatic appearance that they fail to notice a faint, elongated smudge of light about ½° to the northeast. This "little fuzzy" is the 11th-magnitude galaxy **NGC 6207**. I've glimpsed it (barely) in a 3-inch telescope. When you're looking at M13, you see light that crossed a void of some 20,000 light-years. When you turn your gaze to NGC 6207, you're picking up light from an object 46 million light-years away.

Another overlooked deep-space target in Hercules is the globular cluster **M92** (NGC 6341). This gem, slightly smaller and fainter than M13, lies roughly midway between Eta and Iota (ι) Herculis. Again, you're looking at a small hazy ball if you view this globular with binoculars or a small scope, and a sparkling spherical stellar swarm if you apply a large telescope and high magnification.

Hercules offers plenty of intriguing targets for double-star enthusiasts. A particularly striking pair, **Alpha (α) Herculis**, combines a reddish-orange, magnitude 3.5 primary with a blue-green, magnitude 5.4 companion. Only 4.7" separate the pair, so use a magnification of at least 100x for a clean, distinguishable split.

Another pair noted for its colors is **95 Herculis**. This double star sports components of magnitudes 5.1 and 5.2, separated by a little more than 6" — a gap easily breached by the smallest of telescopes (provided the optics are sound). To view both components comfortably, try a magnification of 70x to 100x.

Simple observing project

Would you like to try a simple observing project? Study 95 Herculis carefully and write down the colors you see of its component stars. No fair peeking in any observing guide! I don't want observer bias to influence what you see.

E-mail me (or write to me, care of *Astronomy*) describing the colors (if any) you see, as well as notes on telescope used, magnification, and sky conditions. I'll report the results in a future column.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com.

Next month: We hop aboard "Chaple's Arc." Clear skies!

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BY PHIL HARRINGTON

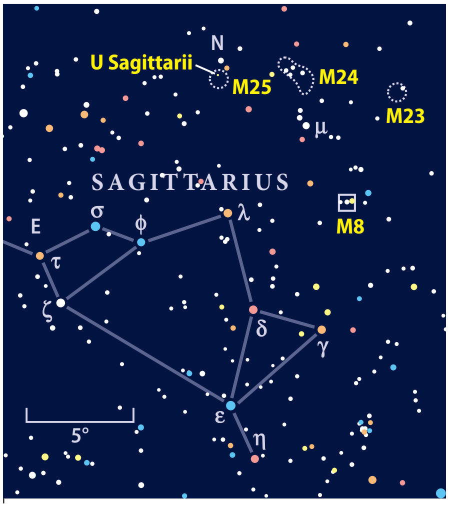
My favorite month

Even though blasts of dry, cold Arctic air make December, January, and February great months for clear skies, my favorite month for observing is August. Whether I'm watching the sky get pummeled by Perseid meteors around the 12th, or I'm just laying back in a chaise lounge and scanning the sky with my binoculars — I love August stargazing.

This month, let's follow the Milky Way's gentle stream southward toward its center in the constellation of Sagittarius the Archer, as we did last August ("I'm a little teapot …"). Back then, we focused on the Lagoon Nebula (M8, or NGC 6523), the Trifid Nebula (M20, or NGC 6514), and the nearby open star cluster M21 (NGC 6531). All three fit easily into the same binocular field and are worth visiting this month if you haven't done so already. Look for them just to the north of the spout of the Sagittarius "teapot" asterism.

Okay, let's pick up where we left off a year ago. From **M8**, binocular-hop to the northeast — that is, above and a little to the left — to the star Mu (μ) Sagittarii. Continue in the same direction an equal distance to the rich star-strewn field known as **M24**. You'll know you're in the right place when you see a small, kite-shape pattern of stars in the middle of the action.

M24 is one of the most unusual members of French astronomer Charles Messier's (1730–1817) catalog. Rather than being considered a separate star cluster, nebula, or galaxy, M24 marks a large clearing in the opaque dust that litters the Milky Way's plane. Known as the Sagittarius Star Cloud, M24 lets us peer inward about 10,000 to 16,000 light-years along the Sagittarius spiral arm of our galaxy. Messier's own description of a "large nebulosity in which there are many stars of different magnitudes" describes the binocular view of M24 perfectly. M24 measures about 1.5° wide.



TOUR M8'S neighborhood on a clear August night using this finder chart.

ASTRONOMY: ROEN KELLY

Two bona fide star clusters stand at attention to either side of M24. **M23** (NGC 6494), found to the west — or right — of M24, harbors about 150 stars compressed into an area that appears as large as the Full Moon (½°). The cluster boasts too many stars to pick out individually, so look for points shining through the cluster's glow.

The second star cluster here lies an equal distance to the east, or left, of M24. Through binoculars, **M25** (IC 4725) should reveal four or five individual stars poking through a dim haze. One of those is a golden Cepheid variable star known as **U Sagittarii**. I enjoy watching U Sagittarii do its thing through binoculars. The star fluctuates between 6th and 7th magnitude every 6.74 days. Look for it to the east-northeast of the cluster's center.

Once you've seen these targets, do as I do, and sit back and scan the area with your binoculars. Star-trolling, as I call it, is a wonderful way to spend a warm August night. Describing the area in his classic book *Astronomy with an Opera-Glass* (1888), Garrett Serviss advised readers to "look carefully all around this region, and you will perceive that the old gods, who traveled this road [the Milky Way was sometimes called the pathway of the gods], trod upon golden sands." Along the way, you're bound to bump into a few unexpected surprises. I've highlighted some of them on Astronomy.com this month, so be sure to stop by and compare notes.

Next month, we'll shoot to Sagitta the Arrow. Till then, enjoy my favorite month. And remember, when it comes to stargazing, two eyes are better than one!

ONLINE EXTRA To learn about additional targets in and around Sagittarius visit www.astronomy.com/toc.

How to hold binoculars

Many of you have asked me to include viewing tips in this column. Great idea! Let's start with a basic one: how to hold binoculars. This sounds easy enough, but there is a right way and a wrong way.

Robert Andrews from Lonetree, Colorado, offers the following advice: "In the Navy, I was taught to cradle the sides of the barrels in my fingers with the hands open and rest the extended thumbs on my cheeks or the side of my face. This results in more stability."

This is a slightly different technique than I'm used to, but I tested it and found it works well. Give it a try. If you have some favorite binocular tips, send them to me at phil@philharrington.net. I'll try to include them in a future column.

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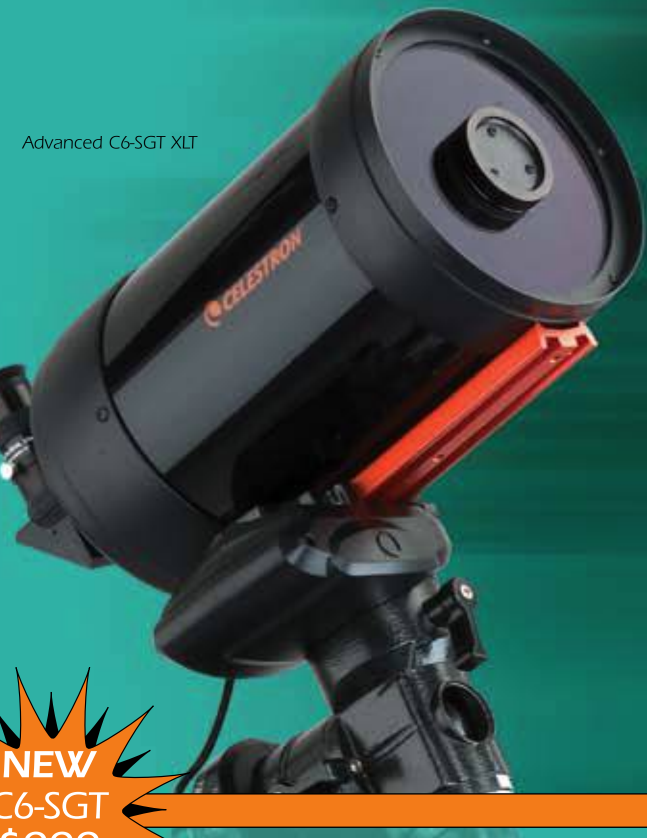
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Serious dunes Cassini scientists say 330-foot-high (100 meters) sand dunes on Saturn's moon Titan form when atmospheric tides from Saturn pile up coffee-ground-size surface grains.

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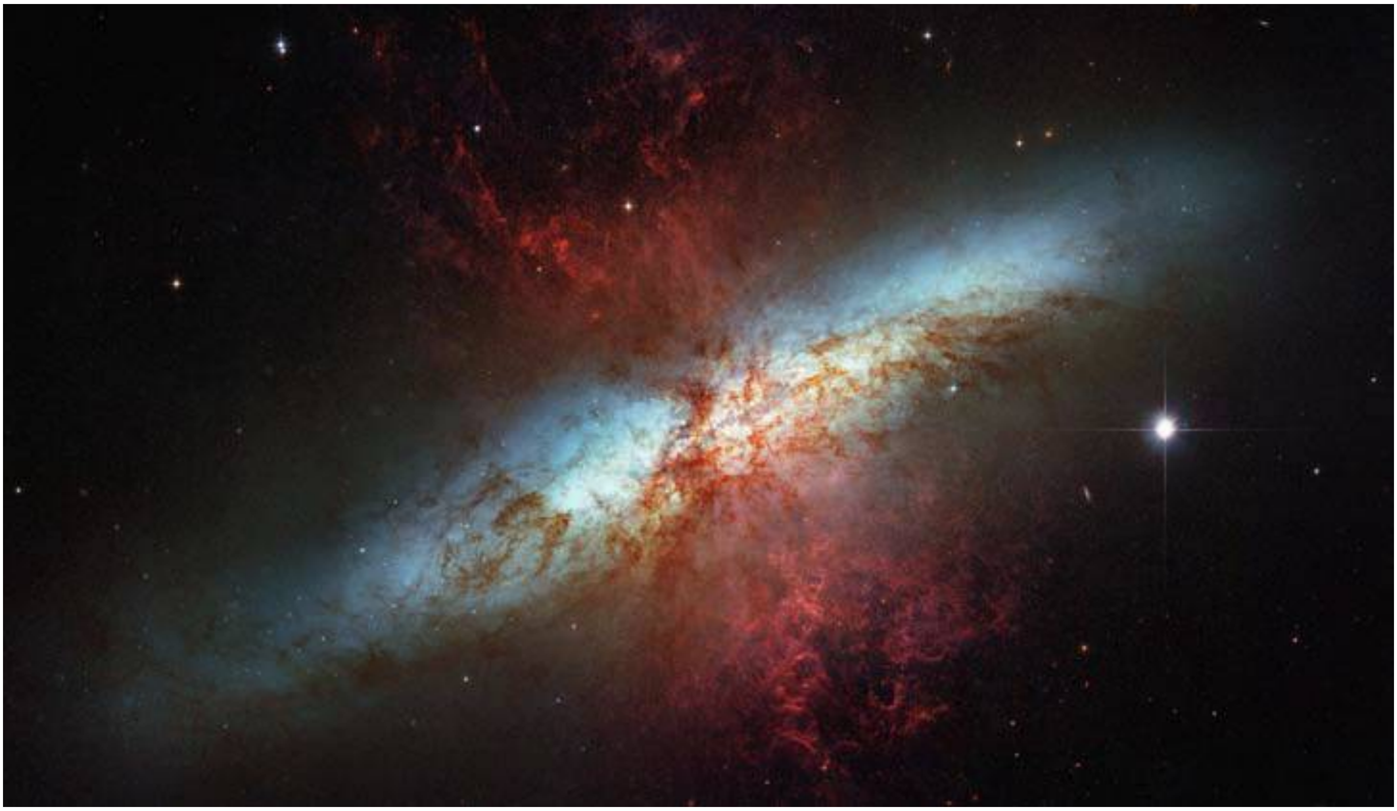
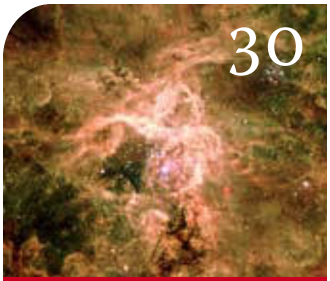


NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

STARBURST. M82 is ablaze with star formation. The galaxy's many hot, young stars blow gas (red) out of its disk and into intergalactic space.



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28 **Small satellite, big potential**

30 **Space "spider" close-up**

31 **Comet crackup**

"Exploding cigar" marks Hubble's 16th year

To celebrate the Hubble Space Telescope's 16th year in space, astronomers released the instrument's most-detailed portrait of M82, also known as the Cigar Galaxy. The galaxy undergoes such prodigious star formation, astronomers once thought it was exploding.

The image "displays celestial fireworks that seem appropriate for 16 years of great Hubble results," says Jay Gallagher of the University of Wisconsin, a member of the observing team. Astronomers class M82, which forms stars at 10 times the Milky Way's rate, as a "starburst" galaxy.

What appear to be fuzzy stars throughout the galaxy are actually star clusters containing as many as a million suns. Recent studies reveal that the galaxies youngest and most luminous clusters are youthful equivalents of the ancient globular clusters that orbit in the haloes of the Milky Way and other galaxies.

A close encounter with neighboring galaxy M81 likely stoked M82's stellar fires by providing a massive influx of hydrogen fuel. M82's many hot, young stars create a "wind" of charged particles that sweeps ionized hydrogen out of the galaxy's disk.

M82 lies 12 million light-years away in Ursa Major. The composite image comprises Hubble optical and infrared observations made in March.

— LAURA BAIRD

“Men love to wonder, and that is the seed of science.” —Ralph Waldo Emerson

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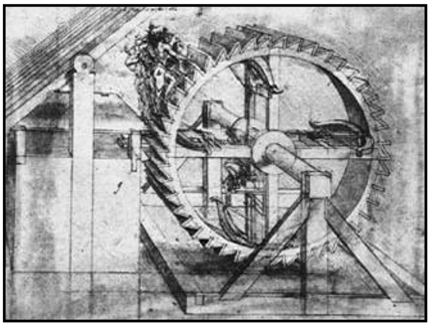

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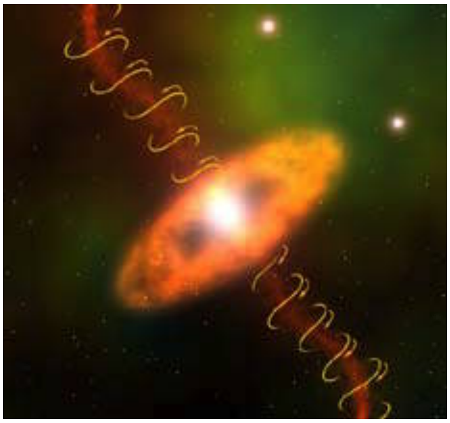


NRAO/AUI/NSF

WRAPPED TIGHT. **This artist's concept depicts magnetic fields shaping jets of water molecules from the star W43A.**

Magnetic fields shape dying star's jets

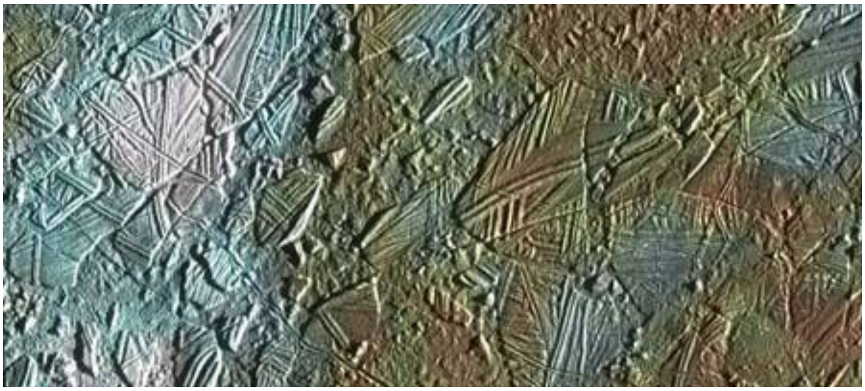
A team of British and Japanese radio astronomers has found direct evidence that magnetic fields sculpt the corkscrew jets of a dying star 8,500 light-years away. The star, W43A in Aquila, is believed to be shedding its mass to form a planetary nebula. This fleeting phase of a Sun-like star's life occurs as the star transitions to its white-dwarf stage. When W43A becomes a white dwarf, it will set its ejected gaseous shell aglow.

A team led by Wouter Vlemmings of England's Jodrell Bank Observatory used the Very Long Baseline Array (VLBA) — a group of ten 82-foot-diameter (25 meters) radio telescopes that spans more than 5,000 miles (8,000 kilometers) — to study how radio waves emitted by water molecules in the star's jets are polarized. These data let the scientists determine the strengths and orientations of the magnetic fields confining the jets. The report appeared March 2 in the journal *Nature*.

Planetary nebulae form when stars about the mass of our Sun shed their outer layers near the end of their lives. But their varied, and often elongated, appearance puzzled astronomers until the 2002 discovery of W43A's water jets. — **LAURA LAYTON**

Moon mission

On May 9, NASA announced it will provide two instruments for India's Chandrayaan-1, a lunar orbiter to launch in late 2007 or early 2008.



NASA/JPL/PIRL/UNIVERSITY OF ARIZONA

ICE RAFTS. Misaligned grooves on Europa's icy surface show that enormous ice blocks have broken free, rotated, and frozen again, like sea ice on Earth.

Defining a mission to Europa

At its fifth annual meeting in February, the Europa Focus Group discussed strategies for exploring Europa, the jovian moon that likely harbors a global ocean beneath its icy surface. The group consists of scientists and engineers organized through Arizona State University and supported by NASA.

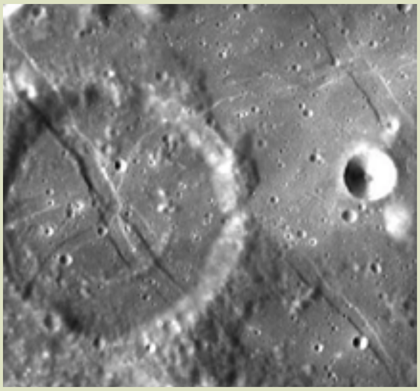
Last year, Congress provided tentative funding for a Europa Orbiter, money withdrawn later by a cash-strapped NASA. Nevertheless, the Europa Focus Group is refining its plans. A new design, which uses Earth and Venus flybys, triples the payload to Jupiter. This allows for more radiation shielding, a bigger suite of science instruments, and the possibility of a piggyback Europa lander.

At the meeting, William McKinnon of Washington University had a revelation about the icy moon. He said the most detailed analysis yet of magnetic-field measurements, taken as NASA's Galileo spacecraft passed Europa, shows the moon has a relatively thin, near-surface layer that's so electrically conductive, the only plausible composition is seawater containing lots of dissolved sulfate salt. — **BRUCE MOOMAW**

SMART-1 snaps wrinkly crater

Rilles — areas where the surface sunk, forming a trench — crisscross the Moon's De Gasparis Crater. Together, the rilles and crater provide an example of relative geological dating: For rilles to cross over the crater, the crater had to be there first.

The European Space Agency's SMART-1 spacecraft imaged De Gasparis January 14. The crater, which lies near Mare Humorum, is named for Annibale de Gasparis (1819–1892), once director of Capo di Monte Observatory in Naples, Italy. — **FRANCIS REDDY**



ESA/SPACEX

RILLES: CRATER DATERS.

Gamma-ray bursts unlikely to toast Earth

A Hubble Space Telescope study of 42 long-duration gamma-ray bursts (GRBs) finds that all but one flared in small irregular galaxies lacking elements heavier than helium. Today's large, metal-rich Milky Way is an unlikely host to an Earth-roasting GRB, astronomers say. — **F. R.**

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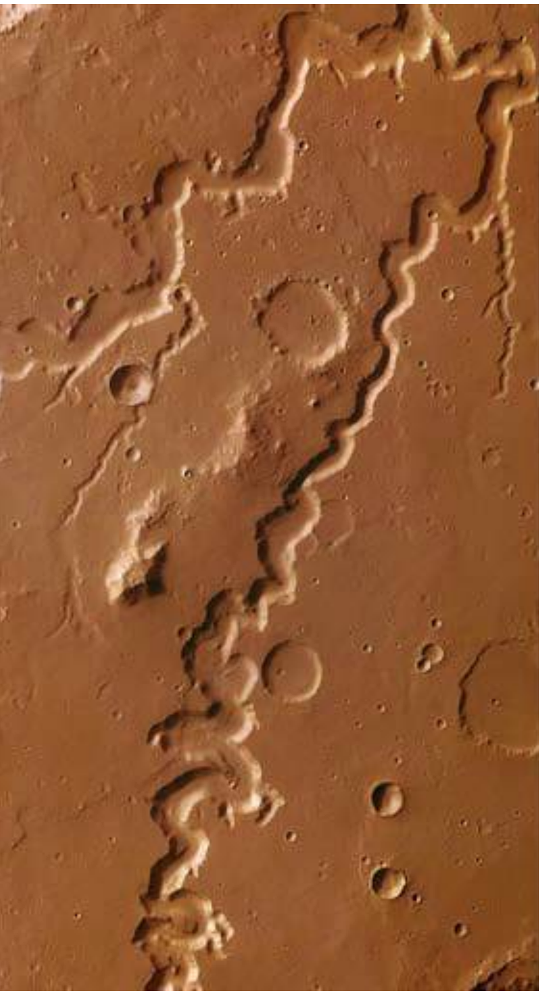


ESA/DLR/FU BERLIN, G. NEUKUM

THE LEVEE WAS DRY. Meanders in Mars' Nanedi Valles suggest long-term flows.

Winding Mars valley

Nanedi Valles, a roughly 500-mile-long (800 kilometers) valley, snakes southwest to northeast in a region of Mars called Xanthe Terra, southwest of Chryse Planitia. In this image, taken by the European Space Agency's Mars Express probe, Nanedi Valles swells from approximately half a mile (0.8 km) to 3.1 miles (5 km) across.

Flanked by steep sides, the valley's flat floor lies as much as 1,640 feet (500 meters) below the surrounding plains. Scientists debate the source, but it seems clear flowing water was involved. Merging branches in the north (top) and the channel's many meanders hint that a long-lasting fluid flow carved the valley. — **F. R.**

Small satellite, big potential

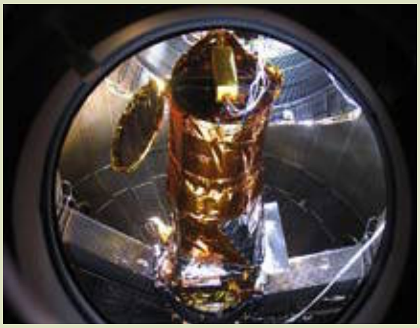
Astronomers like big satellites, and big astronomy satellites can do a lot of specialized observations very well. But a small European satellite named COROT will tackle some crucial astronomical research this fall, and it may pave the way for more specialized follow-on "mini-sats."

With unparalleled sensitivity, COROT will observe about 180,000 stars and watch them over time spans long enough (up to 150 days) to detect patterns in the stars' subtle brightness variations. In theory, such fluctuations can be caused by extremely interesting phenomena, such as transits of planets, passages of starspots, or throbbing of the star's structure. COROT's full name describes what the spacecraft will look for: COnvection, ROtation, and planetary Transits.

The satellite's four wide-field CCD cameras can observe more than 10,000 stars with magnitudes as faint as 15.5 and can detect brightness variations as small as one part per million. At any given time, COROT will watch several hundred stars. Each observation will last 32 seconds and be repeated about every 3 hours. COROT monitors all of the stars for planetary transits, but it checks a few brighter stars more frequently (1 second of observation, approximately once a minute) for seismic activity.

Mission scientists expect to detect a few dozen dimmings with durations consistent with planetary transits. They base this estimate on statistical expectations of earthlike planets and random distributions of their orbital planes — that is, only a few will be "in line" as they pass between their star and Earth. These dimmings will be equivalent to what Earth causes when it passes across the Sun as seen from other stars.

COROT's afocal telescope has a front pupil opening of 10.6 inches (270 millimeters), which gives it a field of view about 3° across. Its charge-coupled devices (CCDs) have a resolution of 2,048 x 2,048 pixels. COROT's observing platform can point to its targets with 1" accuracy.



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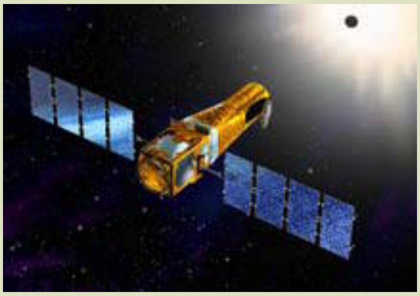
SAT TEST. Last year, engineers tested COROT in a space simulator. Such chambers create the best approximation to space conditions available on Earth.



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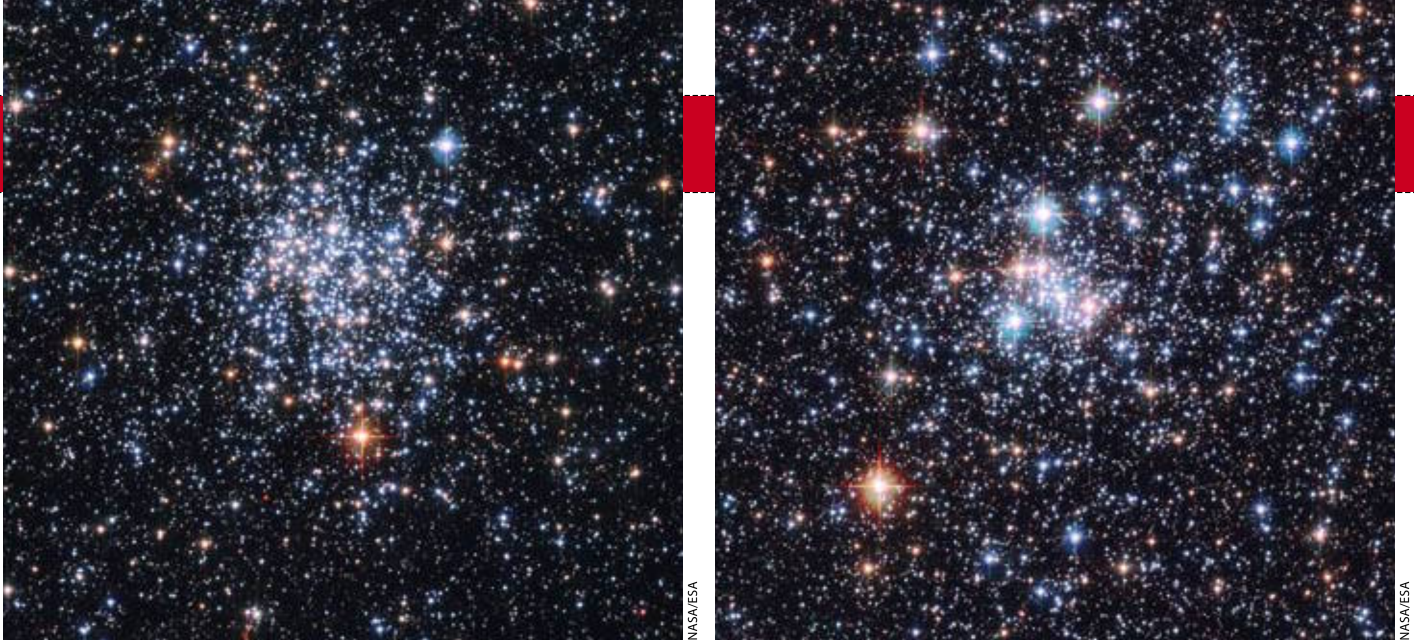
DIM AND DIMMER. COROT will search stars for slight brightness changes caused by transiting planets, stellar vibrations, and spots on a star's surface.

The French-led project kept costs down by using a French PROTEUS spacecraft bus — a standardized frame carrying power, communications, and control systems. The mission will launch on a bargain-basement Russian rocket from Baykonur spaceport in Kazakhstan in October.

If all goes well, COROT will be placed in an orbit carrying it directly over Earth's North and South poles. This means its orbital plane won't be twisted east or west by Earth's equatorial bulge. Instead, the satellite will maintain a constant orientation relative to the celestial sphere. As the Sun progresses across this sphere during the year, the satellite will orient itself so the Sun remains at a right angle to the telescope's line of sight. This means COROT's target areas also will track through the sky.

COROT is designed to last 2.5 years, but the satellite could keep working much longer. There's no danger COROT will run out of targets, despite its rapid-fire pace.
— **JAMES OBERG**



NASA/ESA

NASA/ESA

CELESTIAL GEMS. **Hubble imaged NGC 265 (left) and NGC 290 (right), a pair of rich open star clusters. All of the stars in each cluster formed together, but, in time, they'll drift apart. Both clusters lie in the Small Magellanic Cloud, 200,000 light-years away.**

Hubble images Magellanic jewels

The Hubble Space Telescope's Advanced Camera for Surveys revealed a wealth of detail in NGC 265 and NGC 290, two young clusters in the Small Magellanic Cloud (SMC), a satellite of the Milky Way Galaxy 200,000 light-years away. Each of the 65-light-year-wide clusters contains young stars born from a single gas cloud. As with all open clusters, the stars of NGC 265 and NGC 290 cannot stay together. During the next few hundred million years, as the clusters respond to the gravitational effects of passing molecular clouds and neighboring clusters, their member stars will drift apart and scatter throughout the SMC. — **L. L.**

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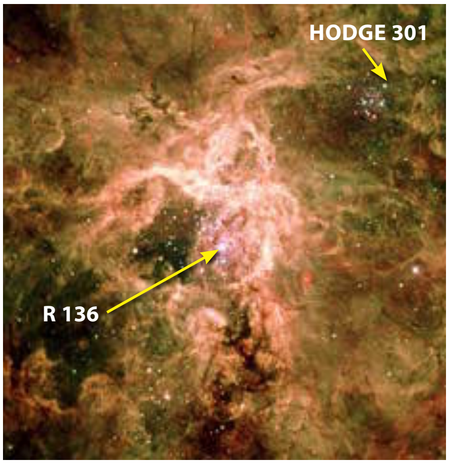


ESO/HENRI BOFFIN

POWDER KEG. **A massive cluster named R 136 shines at the Tarantula Nebula's heart. Stars in neighboring cluster Hodge 301 are 10 times older than those in R 136.**

Space "spider" close-up

In April, the European Southern Observatory (ESO) released an updated composite image of the Tarantula Nebula — a giant cloud of gas and dust that looms above the Large Magellanic Cloud (LMC) like a spider awaiting a meal. In February and March 2003, scientists using ESO's Very Large Telescope captured images of the nebula in multiple wavelengths. Scientists further computer-enhanced these images for the new release.

The Tarantula (NGC 2070) lies 170,000 light-years away in Dorado the Swordfish. About 1,000 light-years across, the Tarantula is the sky's largest emission nebula. Bright arcs of hot gas and dark lanes of dust thread throughout this celestial spider.

A dense cluster of young, massive, hot stars called R 136 forms the arachnid's heart. The 2- to 3-million-year-old cluster generates winds and radiation that shape the nebula and set it aglow.

Several stars surrounding the dense central cluster have masses more than 50 times the mass of our Sun. When these stars eventually explode as supernovae, shock waves from the blasts will trigger more star formation. — **L. L.**

Columbus lab is ready for ISS

ESA/D. DUCROS

ISS DELIVERY. **Europe's Columbus laboratory is slated to link up with the International Space Station in late 2007.**

The European Space Agency's (ESA) Columbus module arrived at the Kennedy Space Center, Florida, May 30. ESA's main contribution to the International Space Station (ISS), the pressurized laboratory is scheduled to be launched on a shuttle and attached to ISS in late 2007.

During the lab's planned 10-year operational lifetime, researchers in Europe, aided by ISS astronauts, will perform up to 500 experiments in life sciences, materials processing, fluid sciences, and fundamental physics. When packed with research equipment, the single-piece module will weigh 16.4 tons (14.9 metric tons). Exterior pallettes will house additional experiments. Columbus measures 21.9 feet (6.7 meters) long and 14.8 feet (4.5m) wide. — **F. R.**

BRIEFCASE

Multisun exoplanets

Nearly one in four planetary systems has more than one sun, say astronomers. Deepak Raghavan of Georgia State University in Atlanta and his colleagues examined 131 exoplanet systems and found that 30 (23 percent) contain at least two stars. The scientists' results will appear in a future issue of *The Astrophysical Journal*. — **L. L.**

Mach 2

Aviation pioneer Scott Crossfield, 84, died April 19 when his Cessna 210A crashed outside Atlanta. In November 1953, Crossfield made flight history when his rocket-powered Douglas D-558-II Skyrocket reached twice the speed of sound. — **F. R.**

Deep dino

The Research Council of Norway reported April 24 that Norway's first dinosaur fossil is the world's deepest yet found. The Plateosaurus knuckle was found in rock 1.4 miles (2.3 kilometers) down an exploratory well in the North Sea's Snorre oil field. — **F. R.**

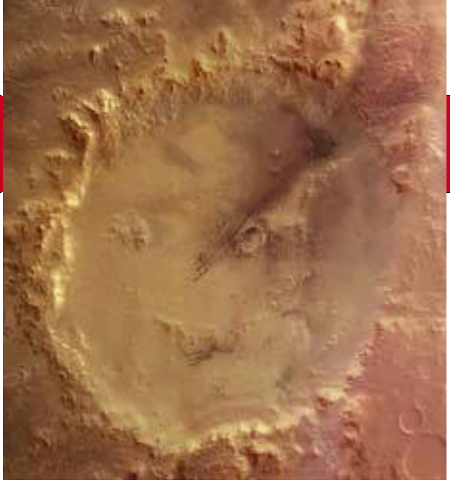
Impact probe hitches a ride

In October 2008, NASA plans to send the Lunar Reconnaissance Orbiter (LRO) to study the Moon's surface in preparation for the return of humans. But, in mid-April, the agency added a secondary payload — the Lunar Crater Observation and Sensing Satellite (LCROSS).

"The LCROSS mission will help us determine if there is water hidden in the permanently dark craters of the Moon's south pole," says Marvin Christensen, manager of NASA's Robotic Lunar Exploration Program.

After launch, LCROSS will separate from LRO, which will enter lunar orbit. As LCROSS continues on a collision course with the lunar south pole, its Earth Departure Upper Stage will separate. The booster will reach the Moon first and impact the lunar surface. Behind it, also on a collision course, is an instrument-laden probe called the Shepherding Spacecraft. The probe will fly through the impact plume and look for evidence of any water released as it, too, descends to the surface. Space- and Earth-based instruments also will be watching both strikes.

This duo is the first in a series of robotic missions NASA plans to send to the Moon. Between 2008 and 2016, such missions will examine and map the lunar surface in preparation for astronauts' return. — **JEREMY McGOVERN**



ESA/DLR/FU BERLIN, G. NEUKUM

WATER CREATED A SMILE.

Miles of smile

This happy face on Mars smiles in Galle Crater. The European Space Agency's Mars Express mission returned the high-resolution images used to create this mosaic.

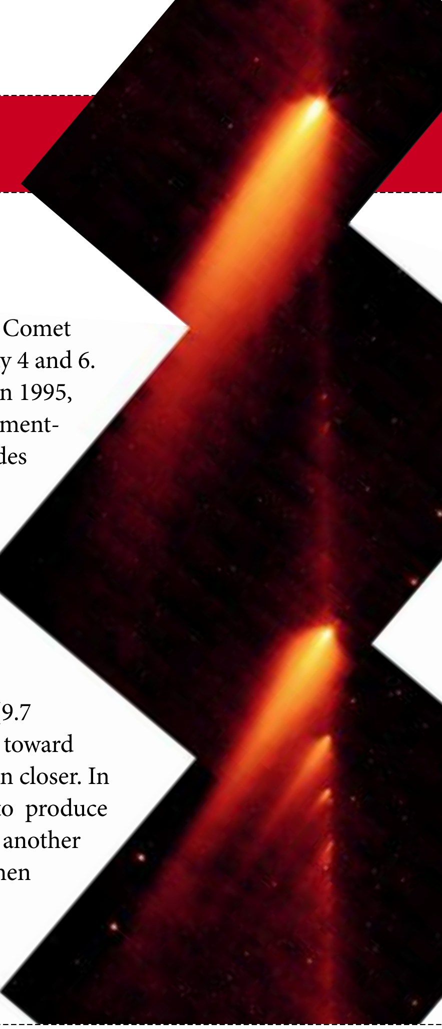
The "smile" comes from the less-eroded southern part of the crater's inner ring; an outcrop of layered sediments stands nearby. Dark catscratch-like gullies run parallel from the inner ring; this suggests liquid water once ran across the surface. Galle, which is 143 miles (230 kilometers) wide, lies east of the Argyre impact basin. — **L. L.**

Comet crackup

NASA's Spitzer Space Telescope imaged the crumbling Comet 73P/Schwassmann-Wachmann 3 (S-W 3) between May 4 and 6. The comet began splintering after it rounded the Sun in 1995, probably as a result of thermal stress, and it's been fragmenting ever since. Spitzer's 24-micron infrared view provides the best look yet at the comet's debris-laden wake.

Warmed by the Sun, dust ejected by the comet glows at infrared wavelengths Spitzer is designed to observe. The image shows at least 36 fragments and their associated dust trails. Warm dust in the comet's orbital plane creates the thin strand that joins the fragments like beads on a string.

The cracked comets passed within 6 million miles (9.7 million kilometers) of Earth in mid-May as they raced toward the Sun. Jupiter's gravity sometimes drives the trail even closer. In 1930, S-W 3's dusty orbit came close enough to Earth to produce the Tau Herculid meteor shower. Astronomers predict another outburst from this erratic shower in 2022 and 2049, when Earth again brushes S-W 3's path. — **F. R.**



COMET PARADE. In mid-May, Comet 73P's dozens of fragments marched past Earth. NASA/JPL-CALTECH/SSC

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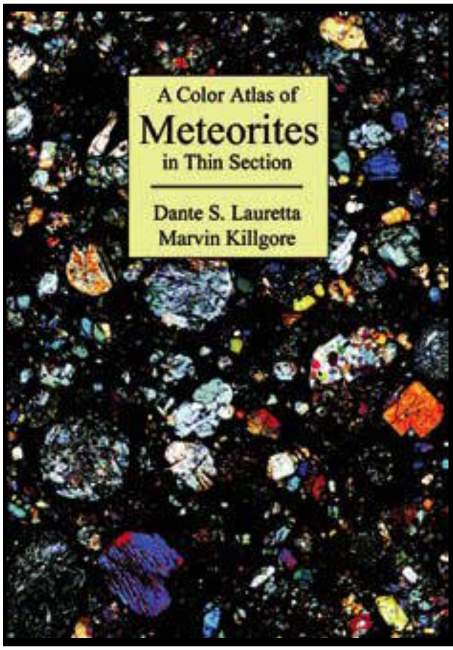

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Unlocking the solar system's past

There's a treasure trove locked inside meteorites, rare particles older than Earth. /// **BY DAVID A. KRING**

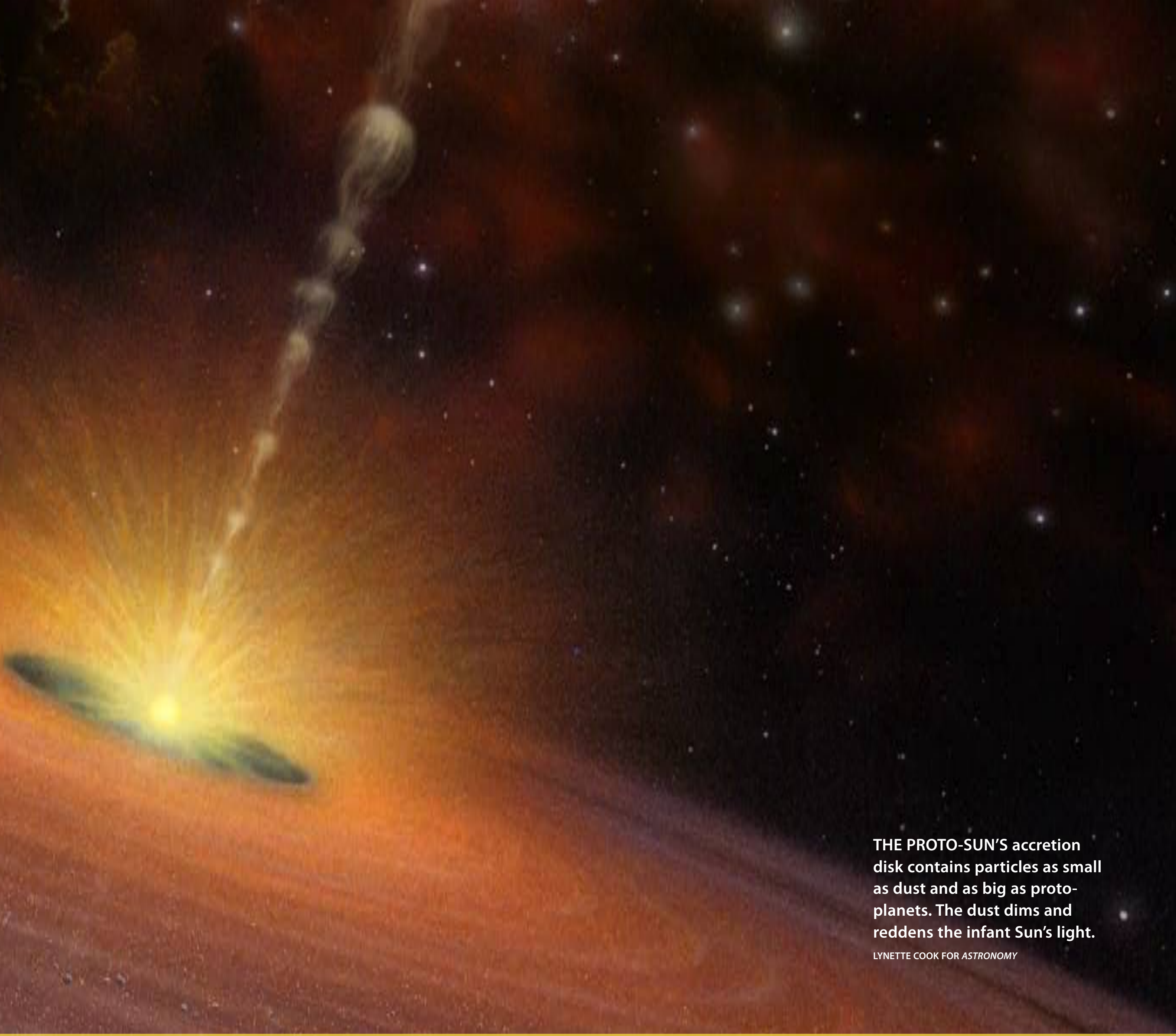
Scientists who study meteorites do so in a tangible way. Rather than looking at objects from afar, they actually hold the products of stars and the remnants of scattered planets in their hands in the form of meteorites. Locked within these rocks from space are tiny pieces of the solar system that predate even the planets.

Tens of thousands of meteorites have been recovered from the far corners of our world. Although these space rocks can be classified in dozens of ways, meteoriticists divide them into two main categories: those that preserve a record of the solar nebula — the growth of microscopic grains to planet-size bodies — and those that preserve evidence of subsequent planetary processes — such as volcanism, interior melting, impacts, and fragmentation.

Clues from chondrites

Scientists tease our origins from primitive stone meteorites, 4.56 billion-year-old relics of the solar system that predate Earth's formation. The jewels of these space rocks are small, millimeter-size orbs called chondrules. Chondrules exist in nearly all chondrite-type meteorites. Within them lie brilliantly colored minerals that tell us the solid orbs were once molten droplets in space.

Olivine and pyroxene crystals, arguably the two most abundant minerals in the solar system, dominate chondrules. Their textures indicate chondrules formed from



THE PROTO-SUN'S accretion disk contains particles as small as dust and as big as protoplanets. The dust dims and reddens the infant Sun's light.

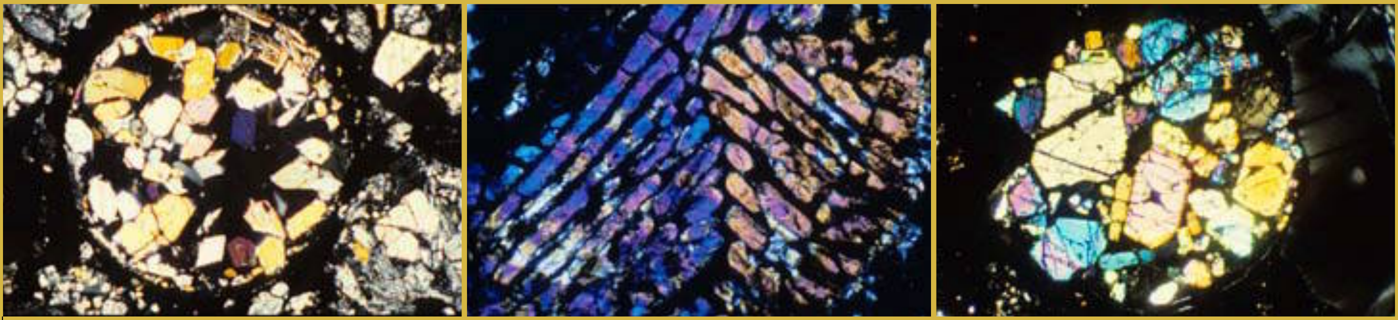
LYNETTE COOK FOR *ASTRONOMY*

dustballs that were somehow flash-melted in episodes that exceeded 1,880° Fahrenheit (1,027° Celsius). Some chondrules show signs of repeated exposure to brief, high-temperature conditions. These "hot zones" may have been up to a few thousand kilometers across, which are short distances on a cosmic scale. In fact, chondrules record heating events lasting as little as an hour that occurred over 4 billion years ago as the solar system formed. Yet, despite these detailed glimpses into the origins of our planetary system, the nature of these hot zones remains a mystery. Scientists have proposed transient shock waves, lightning bolts, stellar jets, and several other possible processes, but no one knows exactly what flash-melted the chondrules.

David A. Kring *is an associate professor of planetary sciences, associate professor of geosciences, the director of the NASA/University of Arizona Space Imagery Center, and the founding director of the University of Arizona Meteorite Recovery Program.*

Chondritic meteorites hold another prize, too — objects called refractory inclusions. Refractory elements condense at high temperatures, so these inclusions also tell us of hot times in the forming solar system.

Sometimes, temperatures rose so high in the solar nebula that dust evaporated, leaving refractory minerals behind. At other times, temperatures dropped so low that new dust condensed from the gas. Both materials have unusual compositions enriched in elements like calcium, aluminum, and titanium.



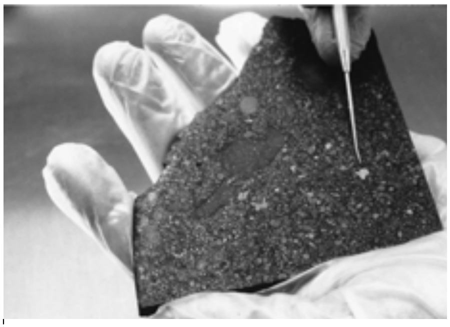
PRIMORDIAL CRYSTALS called chondrules are spherical clumps of mineral crystals that formed before Earth existed. Scientists found this chondrule (left) in the Semarkona meteorite, which fell in India in 1940. This chondrule (center) came from the primitive Mokoia meteorite, found in New Zealand in 1908. Cat Mountain meteorite, found in Arizona in 1980, contained this chondrule sample (right). DAVID A. KRING

Planetary scientists can't say whether refractory inclusions formed in the same region of the solar nebula as the chondrules. It's possible, though, that they give us an even earlier slice of the solar system. Some models suggest refractory inclusions formed up to 4 million years before chondrules.

From dust to planets

Eventually, space became ever more filled with chondrules; they bumped into each other and accreted to form larger particles. The growing particles sometimes encountered refractory inclusions and lots of micron-size dust from the nebula. This material produced a fine-grained matrix between chondrules. Together, clumps of chondrules, matrix material, and refractory inclusions continued to bump into each other, forming larger objects over time. It's from these cosmic sediments that our solar system's first planet-size bodies formed.

However, the evidence so far paints a picture that's far from complete. Primitive meteorites come from the asteroid belt, so they preserve clues about the protoplanetary gas and dust cloud that extended from about 2 to 5 AU (an AU is the average Sun-Earth distance). This is a very selective sample in a planetary system that spans about 40 AU.



CLUES FROM the solar nebula are locked inside the Allende slab, a meteorite that fell in Chihuahua, Mexico, in 1969. DAVID A. KRING

Rough neighborhood

But meteorites hold other clues about our solar system's origin. Although the bulk of the material in them formed in the solar nebula, meteorites also contain tiny pieces of interstellar matter left over from the formation of our nascent star.

Our solar system emerged from a molecular cloud rich with dust and a complex assemblage of gas molecules. Although hydrogen and helium dominated the cloud, cold temperatures of about –442° F (–263° C) enabled molecules like hydrogen cyanide, water, ammonia, and formaldehyde to form. Several denser cloud cores were buried within the molecular cloud. One of those cores became gravitationally unstable and began to collapse. The core flattened and spun faster, eventually forming a disk that surrounded the proto-star that would become our Sun. Scientists call the disk the solar nebula, and most of its mass ended up in the growing star.

CHONDRITES PRESERVE molecular-cloud-core dust remnants.

The collapse occurred quickly, within 100,000 years, which is an incredibly short interval when compared to geologic timescales. During that brief span, a 15,000-AU-diameter cloud core collapsed to form a 1-AU-thick solar nebula. Temperatures in the disk were hotter than in the molecular cloud core, typically over 1,000° F (538° C) in the region of the disk that would become the inner solar system.

Primitive chondrites preserve molecular-cloud-core dust remnants. Stellar atmospheres produced these grains, so the dust helps us identify the types of stars that existed in the region of space where our Sun was born. This stardust contains several minerals: nanodiamonds, graphite, silicon carbide, silicon nitride, corundum, hibonite, spinel, pyroxene, olivine, and amorphous glass with embedded metal and sulfide particles.

Meteorites also contain traces of nuclear reactions in stars that provide additional clues about stellar activity at the birth of our Sun. Radioactive isotopes that existed when our solar system formed — aluminum–26, iron–60, manganese–53, and iodine–129 — have now decayed, but their chemical fingerprints linger in chondritic meteorites. Taken together, stardust and these isotopes suggest the solar system formed in a seething cauldron of stellar activity and interstellar debris.

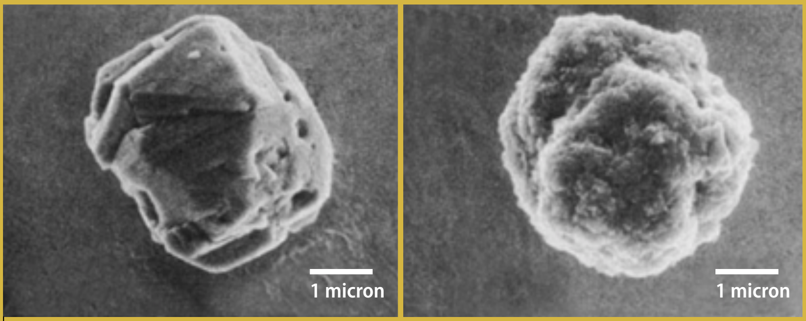
Stellar birthplaces are dynamic environments. Our own solar system's origin was probably no less dynamic or colorful. Evidence points to fast-evolving, high-mass neighbors, such as Wolf-Rayet and their ensuing type II supernovae. Some may have been 15 times more massive than our Sun.

Building planets

These same short-lived isotopes, plus ones that are longer-lived like potassium–40, uranium–235 and –238, and thorium–232, warmed planets from the inside out as the planets formed in the solar nebula. The faster accretion occurred, the more short-lived isotopes contributed to the process. Each planet's size was also important. Smaller planets radiated this internal heat to space more efficiently. They have

THE ORION NEBULA (M42) is the nearest hotbed of star formation. Here, stars form out of copious amounts of gas and dust, creating disks of debris that may make planets.

NASA/ESA/M. ROBBERTO (STScI/ESA)/HST ORION TREASURY PROJECT TEAM



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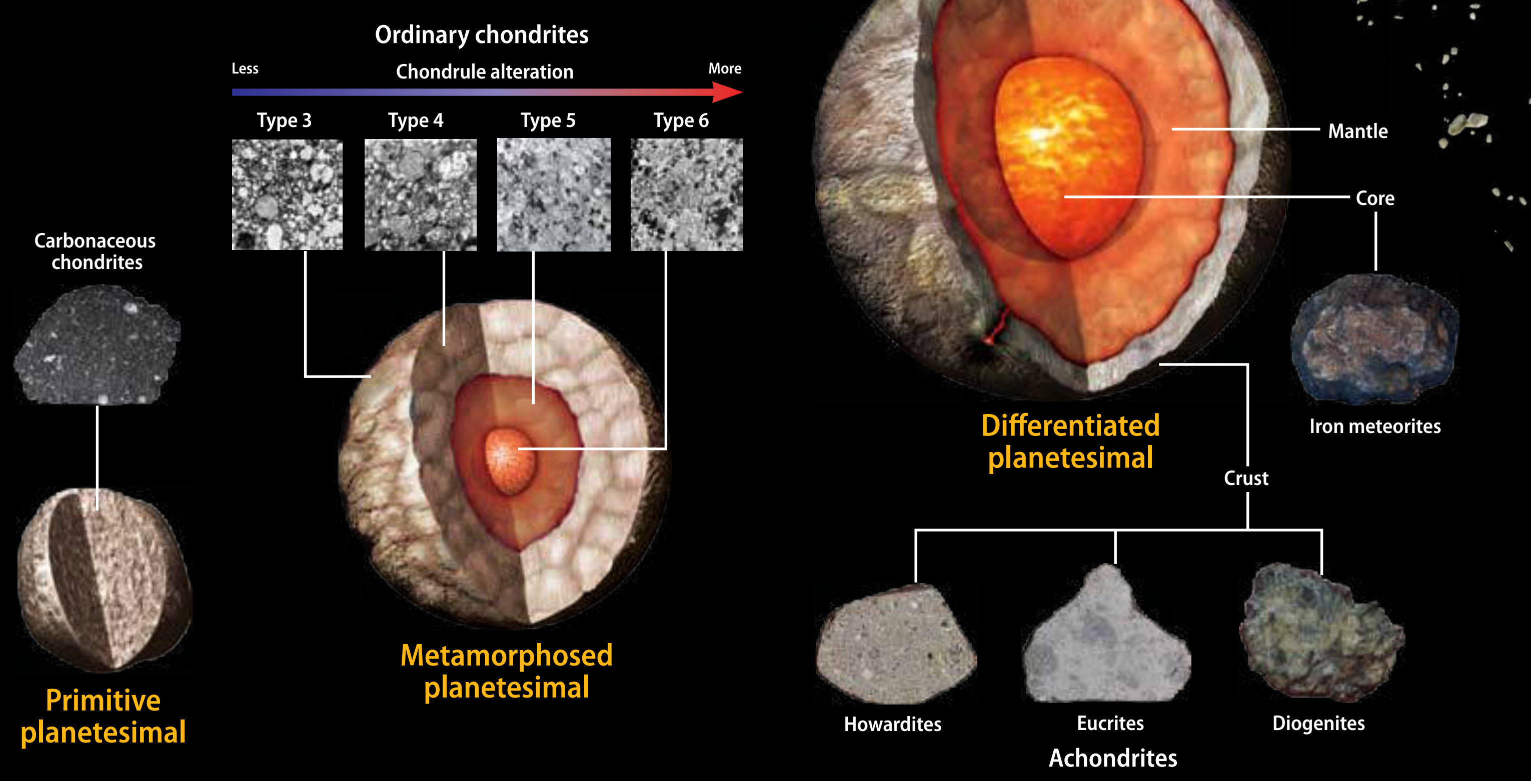
STARDUST IS composed of micron-size grains of (left) silicon carbide and (right) graphite. These tiny particles, which formed in the atmospheres of other stars before our solar system existed, are found in primitive meteorites.

NASA/RICE UNIVERSITY/C. R. O'DELL

PROPLYDS ARE protoplanetary disks that surround the infant solar systems of other stars. These proplyds lie 1,500 light-years away in the Orion Nebula.

Meteorite origins



DIFFERENT METEORITE classes reveal different parts of the solar system's history. Ordinary chondrites are meteorites that formed in metamorphosed planetesimals — bodies that partially melted and then recrystallized. Iron meteorites and achondrites come from planetesimals that experienced complete melting. These bodies differentiated into layers: an iron core, a mantle, and a crust. *ASTRONOMY*: ROEN KELLY; ORDINARY CHONDRITE PHOTOS: W. R. VAN SCHMUSS AND J. A. WOOD; HOWARDITE, DIOGENITE, AND MARS PHOTOS: ROBERT HAAG; ALL OTHER IMAGES BY DAVID A. KRING

larger surface areas relative to the volume of matter.

Both factors explain why some planetesimals preserved chemical snapshots of the young solar system. Larger planets became self-insulating. They heated up — in some cases dramatically — to form completely molten objects, which destroyed clues to the past.

Some bodies fell somewhere between the two extremes. They weren't large enough to melt completely, but they did melt some. Minerals in these intermediate-size bodies were altered by heat — their chemical compositions changed.

Examples of all these planetary forms can be found in meteorites, but heat-altered samples are the most abundant, representing more than 90 percent of all recovered meteorites. Called "ordinary" chondrites, a subtype of chondrite meteorites, they are wonderful specimens of early planetary material. Scientists can easily see that planets accreted from both rocky and metallic components because heating enlarged the planets' metal particles. The most intensely heated planets underwent differentiation: a process in which denser metal sinks to form an iron-rich core, leaving behind a mantle and/or crust of lighter, silicate-rich material.

These clues tell us planets form fast. Analyses of some isotopes in meteorite samples, plus samples from Earth, the Moon, and Mars, have put the squeeze on planetary-accretion timescales.

Scientists used to say small planets formed in 10 million years, while larger planets took 10 times longer. In contrast, several scientific groups now suggest small planets accreted, differentiated, and even produced lava flows within 3 million years. Large planets like Earth may have formed in less than 30 million years, with their cores established just 50 million years after the Sun itself.

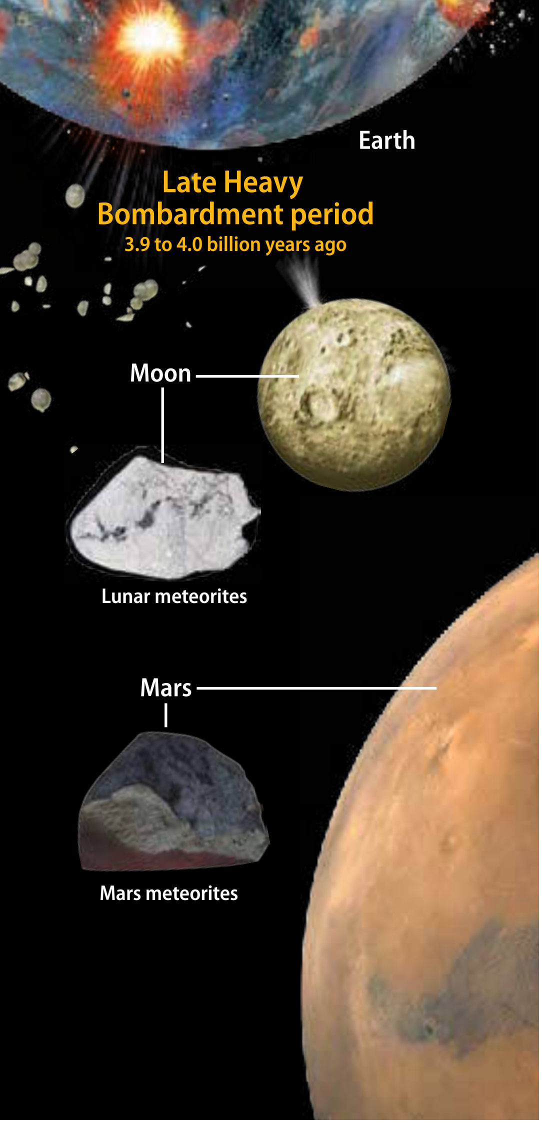
Bumper-car evolution

The young solar system must have been incredibly violent. Collisions with large objects occurred frequently. One of the largest of these events appears to have occurred when a body twice the Moon's diameter hit the growing Earth. The ejected debris accreted to form the Moon.

The collisional evolution of the solar system and its effect on Earth did not cease, however. Earth and the other terrestrial planets continued to be the targets of impacting asteroids and comets. Perhaps the most famous example is the Chicxulub impact, which occurred 65 million years ago and may have extinguished most of the life that existed during the Cretaceous Period, including the dinosaurs. Meteorites from the Moon, Mars, and asteroid belt provide new measures of the pulse of collisional evolution.

Pelted Moon

The collisional-evolution theory began with an Apollo-era study of lunar samples. When scientists analyzed the ages of samples astronauts collected, they discovered two important findings: Lunar crust was thoroughly transformed about 3.9 billion years ago, and



a large number of impact events at the same time produced the Moon's large — in some cases, greater than 621 miles (1,000 km) in diameter — impact basins.

These findings led to the development of the lunar-cataclysm hypothesis, in which scientists proposed the Moon (and, thus, Earth) was severely bombarded about 3.9–4.0 billion years ago. Skeptics, however, pointed out that the Apollo landing sites were clustered in a small area of the Moon and may have provided a biased sampling of melts from only a couple of impact basins.

THE LUNAR CRUST was thoroughly transformed about 3.9 billion years ago.

Newly discovered lunar meteorites provide a new means of testing the hypothesis of lunar cataclysm. These samples were ejected from random locations on the Moon and, thus, represent a better sampling of the lunar crust and its impact record. Analyses of impact melts in these meteorites support the lunar-cataclysm hypothesis, which suggests there was a relative dearth of impact events about 4.0–4.4 billion years ago, followed by an intense bombardment about 3.9–4.0 billion years ago. The duration of this bombardment is estimated to be 20–200 million years, the end of which coincides with the earliest detection of life on Earth in 3.85-billion-year-old rocks.

An analysis of martian meteorite Allan Hills 84001, the only sample from Mars' impact-cratered highlands, also produced a 3.9-billion-year-old impact age. This suggests the lunar cataclysm should more properly be called an inner solar system cataclysm, a time when all terrestrial planetary surfaces were bombarded. The source of most of the debris that hit planets appears to be the asteroid belt, rather than comets.

Although the cataclysmic bombardment was sufficient to resurface Earth, it was not large enough to supply the existing water reservoir. This implies most of Earth's water had already formed and the elements needed for life had already arrived.

Environmental conditions at Earth's surface during the bombardment would have been frightful. The pounding produced more than 20,000 impact craters with diameters from 12 to 3,107 miles (20 to 5,000 km), including 40 impact basins 600 miles (1,000 km) in diameter.

It would have been a challenging, if not impossible, time for life. During the largest of these impact events, the blue seas that covered the planet may have been temporarily vaporized. These same impact events also produced vast subsurface hydrothermal systems suitable for primitive life to form. Fortunately, the bombardment was short-lived and a relatively tranquil Earth evolved, its oceans blue again.

The peculiar spike in the impact rate, approximately 500–600 million years after solar system formation, is puzzling. Something unusual must have occurred to stir up the asteroid belt and fling debris throughout the inner solar system. A leading theory suggests resonances swept through the asteroid belt, perturbing asteroids' orbits into Earth-crossing streams.

Could similar processes occur in other young planetary systems? The answer seems to be yes. Astronomers using the Spitzer Space Telescope have detected circumstellar debris disks created several hundred million years after their central stars formed. This implies the formation of planetary systems similar to our own.

Thus, we have come full circle. We began with meteoritic clues of how other stellar systems affected the origin and evolution of our own solar system. We are now uncovering meteoritic clues that will help us better understand the origin and evolution of other stars and their planetary systems. Imagine: All of this information can be held in the palm of your hand.

GLOSSARY

ACCRETION:
The process of building solids from the accumulation of material.

CHONDRITE:
A type of rock containing spherical orbs of mineral crystals.

CHONDRULE:
Millimeter-size orbs of brilliantly colored minerals found in chondrite meteorites.

DIFFERENTIATION:
A process in which denser metal sinks to form an iron-rich core, leaving behind a mantle and/or crust of lighter, silicate-rich material.

ISOTOPE:
A combination of similar chemical elements that have different atomic numbers and physical properties.

PLANETESIMAL:
Small solid bodies, also protoplanets, within a solar nebula that grow as matter accretes.

REFRACTORY INCLUSION:
Residues and condensates enriched in elements like calcium, aluminum, and titanium found in meteorites.

SOLAR NEBULA:
The Sun's accretion disk.

ONLINE EXTRA See what Stardust's comet samples say about the early solar system at www.astronomy.com/toc.

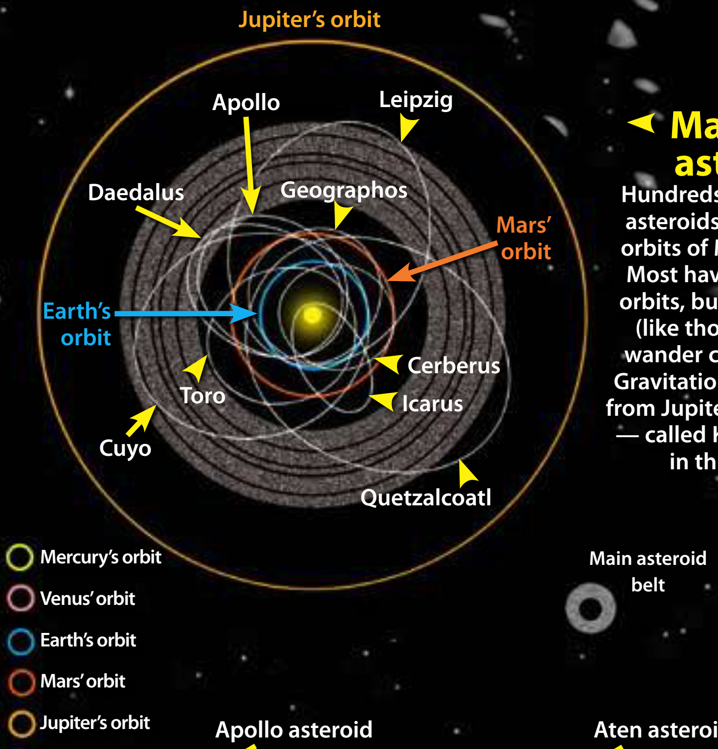
Between a rock and a gas

Mars and Jupiter bracket a belt of mini-planets where action is the name of the game. /// BY RICHARD TALCOTT; ILLUSTRATION BY RON MILLER

On January 1, 1801, Italian astronomer Giuseppe Piazzi (1746–1826) spotted an object not on his star charts. Over the next 6 weeks, he watched it trek through Taurus. It moved slower than Mars and faster than Jupiter — a sure sign it resided between those two planets.

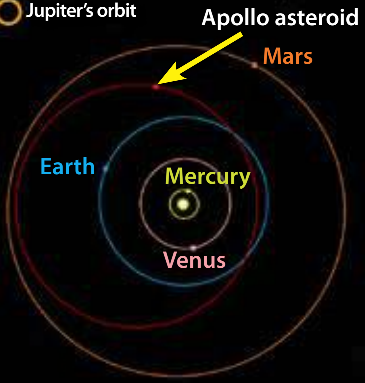
And then Piazzi fell ill. By the time his reports reached northern Europe, the object was lost in the Sun's glare. Hearing of the discovery, German mathematician Karl Friedrich Gauss (1777–1855) devised a new method for calculating orbits from limited observations. Later that year, the object turned up right where Gauss predicted.

Most scientists thought the object was a planet occupying the wide gap between Mars and Jupiter. But within a year another was found, then another, and another. Today, more than 600,000 of these "asteroids" are known. Most lie between Mars and Jupiter, but some cross Earth's orbit and others inhabit the frigid outer solar system. ◼


Jupiter's orbit
Apollo
Leipzig
Daedalus
Geographos
Mars' orbit
Earth's orbit
Cerberus
Icarus
Toro
Cuyo
Quetzalcoatl
Mercury's orbit
Venus' orbit
Earth's orbit
Mars' orbit
Jupiter's orbit
Main asteroid belt

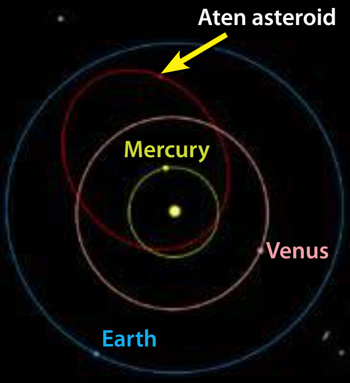
Main-belt asteroids

Hundreds of thousands of asteroids lie between the orbits of Mars and Jupiter. Most have nearly circular orbits, but a small number (like those highlighted) wander closer to the Sun. Gravitational perturbations from Jupiter create thin gaps — called Kirkwood gaps — in this main belt.


Apollo asteroid
Mars
Earth
Mercury
Venus

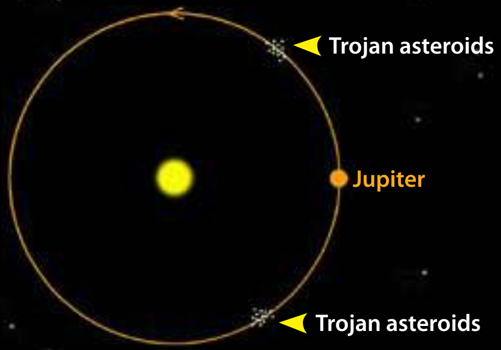
Apollos

An Apollo asteroid (red) comes inside Earth's orbit at its closest to the Sun, but its average distance lies beyond our planet.


Aten asteroid
Mercury
Venus
Earth

Atens

An Aten-class asteroid (red) is one whose average distance from the Sun lies inside Earth's orbit. Many Atens do cross our orbit, however.


Trojan asteroids
Jupiter
Trojan asteroids

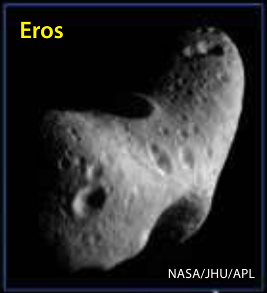
Trojans

These asteroids share the orbit of Jupiter. They remain approximately 60° in front of and behind the giant planet as it orbits the Sun.

Annefrank

NASA/JPL

Stardust imaged this 5-mile-wide (8 km) rock in 2003.



Eros

NASA/JHU/APL

NEAR-Shoemaker orbited this near-Earth object starting in 2000.

Gaspra

NASA/JPL

The Galileo spacecraft captured the first asteroid close-up in 1991.

Ida

NASA/JPL

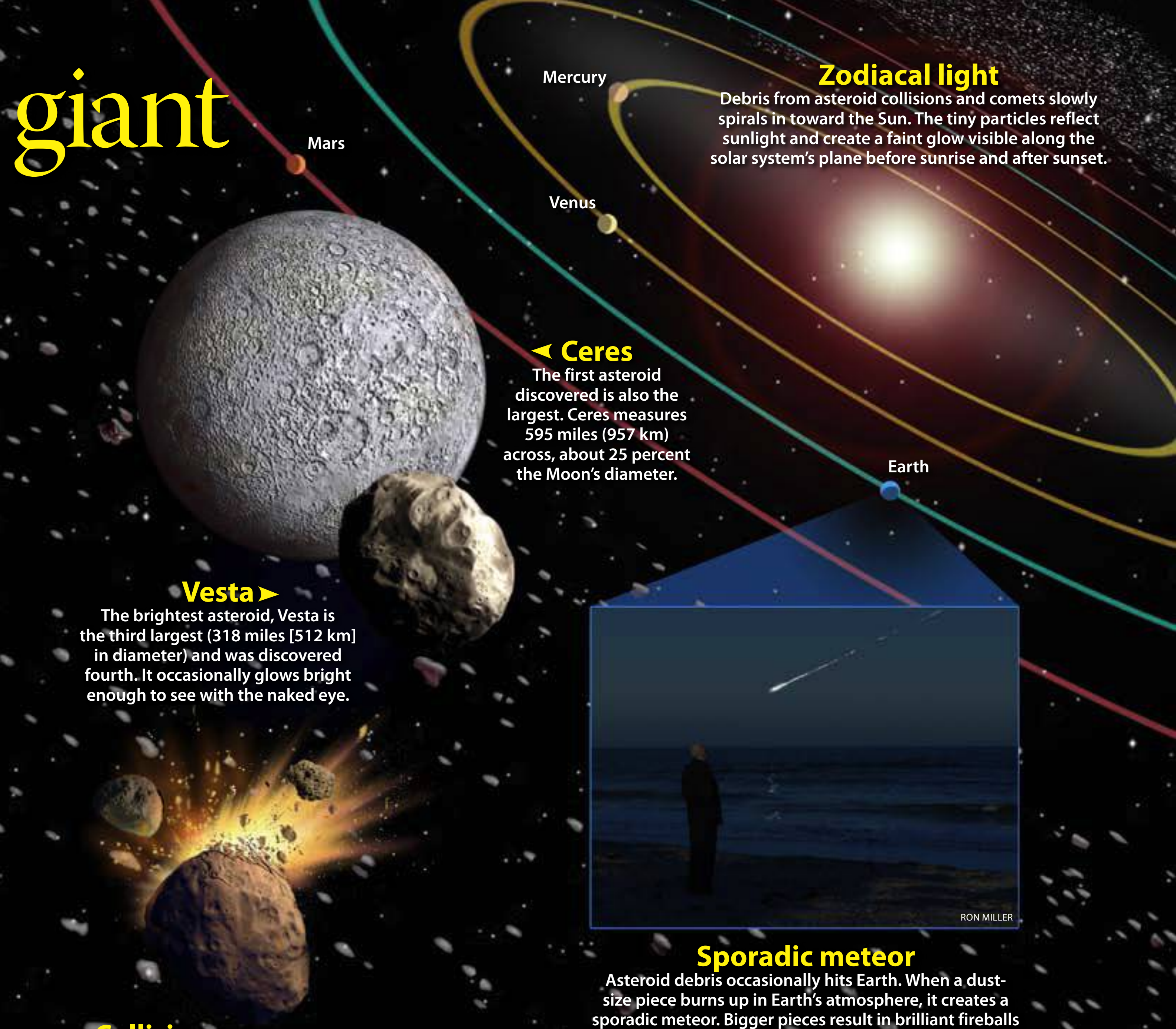
In 1993, Galileo discovered the first asteroid moon — Dactyl — orbiting Ida.

Mathilde

NASA/JHU/APL

NEAR-Shoemaker flew past this heavily cratered object in 1997.

giant



Zodiacal light

Debris from asteroid collisions and comets slowly spirals in toward the Sun. The tiny particles reflect sunlight and create a faint glow visible along the solar system's plane before sunrise and after sunset.

◄ Ceres

The first asteroid discovered is also the largest. Ceres measures 595 miles (957 km) across, about 25 percent the Moon's diameter.

Vesta ►

The brightest asteroid, Vesta is the third largest (318 miles [512 km] in diameter) and was discovered fourth. It occasionally glows bright enough to see with the naked eye.

RON MILLER

Sporadic meteor

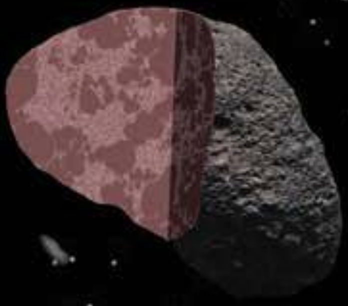
Asteroid debris occasionally hits Earth. When a dust-size piece burns up in Earth's atmosphere, it creates a sporadic meteor. Bigger pieces result in brilliant fireballs and may survive to reach Earth's surface as meteorites.

Collisions

When asteroids collide, fragments fly off in all directions. If two pieces have nearly the same speed and path, they may form a double asteroid or an asteroid with a small moon.

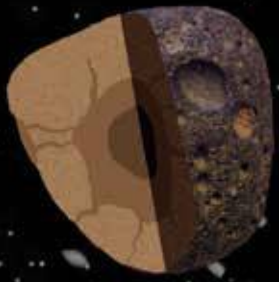
ISAS/JAXA

Hayabusa flew alongside this boulder-strewn object in 2005.



Rubble pile

Some asteroids, like Itokawa, are a collection of large and small components held together weakly by their mutual gravity.



Solid body

Other asteroids, like Vesta, appear to be differentiated objects. Heavy elements have sunk to their cores, while lighter elements have risen to their surfaces.

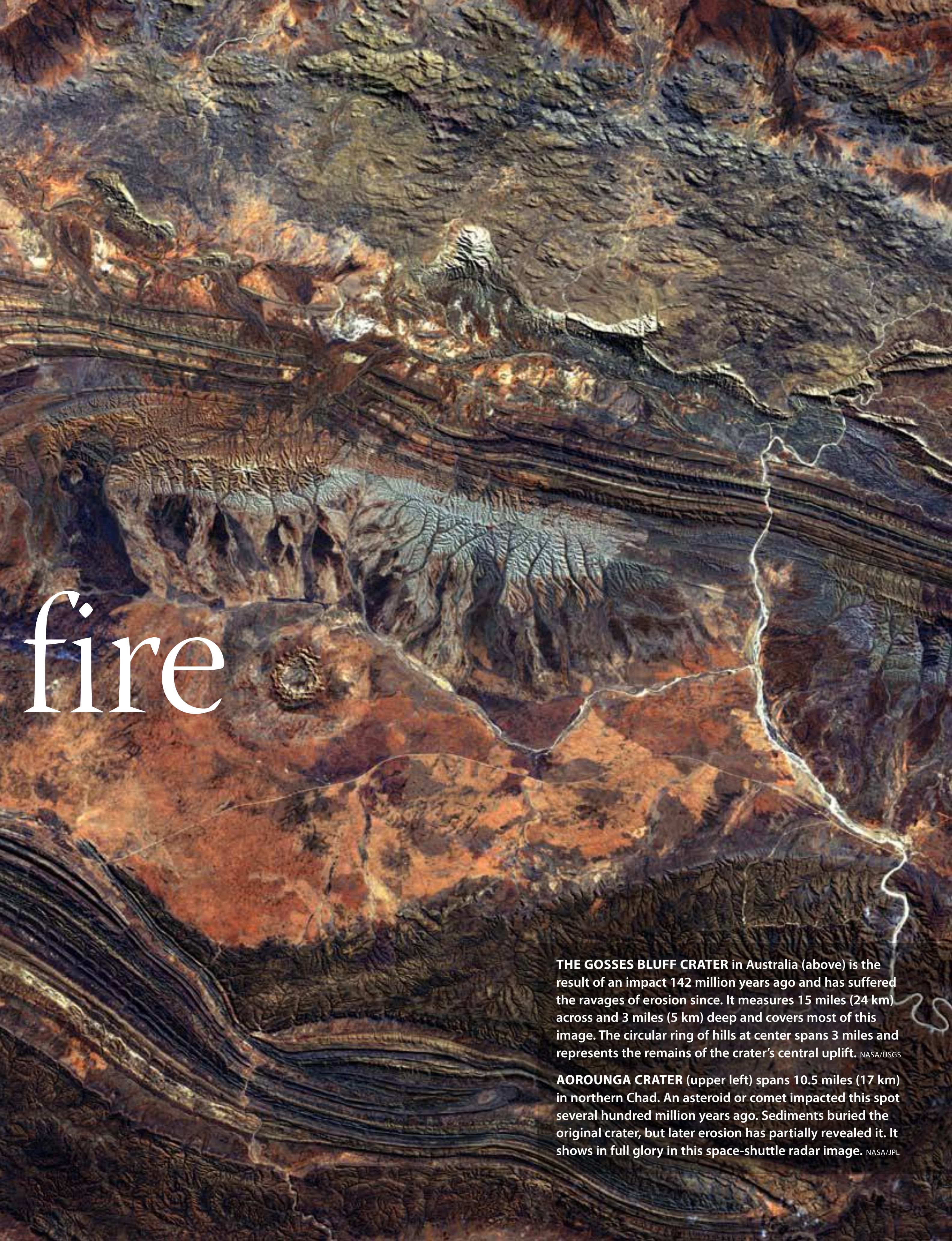
Astronomy magazine

Earth under

Our planet's surface is riddled with craters formed by high-speed cosmic impacts. /// BY MIKE REYNOLDS

Most of us are familiar with the major features of the world — oceans, continents, mountain ranges, valleys, deserts, rivers, lakes — the list goes on and on. One feature not likely to make this list is an impact crater. Craters appear few and far between on Earth's surface, and most of the obvious ones formed from volcanic activity, not impacts. Yet, that doesn't mean impacts haven't occurred. The evidence lies all around us — on Earth and on its neighbors.

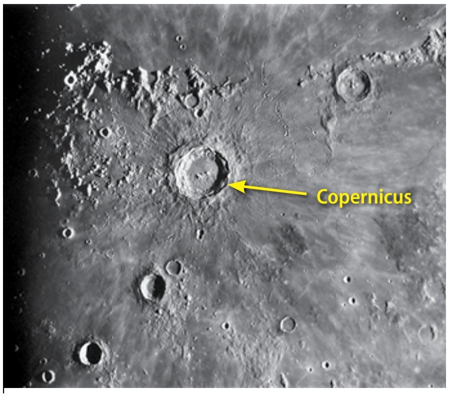
Take a look at the Moon through a small telescope, and one thing stands out even to casual observers: Craters cover its surface. Time and time again, rocks have pummeled the Moon. Our satellite's pockmarked face is evidence that our solar system was and still is an active place. Spacecraft views of our planetary neighbors provide the same image of impacts and cratering.



fire

THE GOSSES BLUFF CRATER in Australia (above) is the result of an impact 142 million years ago and has suffered the ravages of erosion since. It measures 15 miles (24 km) across and 3 miles (5 km) deep and covers most of this image. The circular ring of hills at center spans 3 miles and represents the remains of the crater's central uplift. NASA/USGS

AOROUNGA CRATER (upper left) spans 10.5 miles (17 km) in northern Chad. An asteroid or comet impacted this spot several hundred million years ago. Sediments buried the original crater, but later erosion has partially revealed it. It shows in full glory in this space-shuttle radar image. NASA/JPL

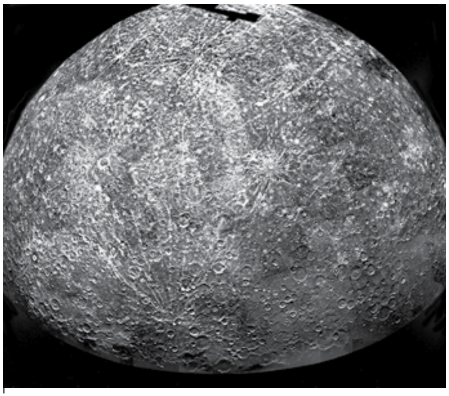


FROM CONSOLIDATED *LUNAR ATLAS* (LPL/UA)

THE CRATER Copernicus marks the spot where an asteroid smashed into the Moon's surface 800 million years ago. Debris thrown out from the initial impact created many of the small craters surrounding it.

FROM CONSOLIDATED *LUNAR ATLAS* (LPL/UA)

THE MOON'S southern highlands are chock-a-block with impact craters dating from more than 4 billion years ago. Younger craters dot the floors and rims of older, degraded craters.



NASA/JPL

MERCURY looks a lot like the Moon, with craters covering most of the visible surface. The high crater density implies Mercury's surface is among the oldest in the solar system.

Planetary scientists now realize that rocks of various sizes have been colliding with solar system members since the whole system formed some 4.65 billion years ago. Some of the impacting bodies were quite small and hardly made a dent. Others were miles across and caused major changes on the impacted body's surface. Our Moon owes its very existence to a colossal impact; it formed from debris created when a Mars-size object struck the early Earth.

Even some of the small objects in our solar system — asteroids and comets — show numerous impact scars. It would come as a huge surprise if Earth were unique in the solar system as the only rocky object without impact craters. No need to worry — telltale signs of cratering in both the distant and recent past exist. The evidence, however, is often subtle.

The solar system's impact history can tell us about Earth's past as well as give us a peek into the future. We know the early solar system was a far more dangerous place than it is today. Objects with ancient surfaces, like the Moon and Mercury, show impacts used to happen much more frequently than they do now. Astronomers estimate as little as 5 percent of the solar system's original number of asteroids still remain. The rest were casualties, blown to smithereens after losing a game of celestial chicken.

MOST ASTEROIDS WERE blown to smithereens after losing a game of celestial chicken.

Chicken Little

Perhaps the most surprising discovery to come from spacecraft reconnaissance of our solar system has been the degree of cratering found on its bodies. Although, in hindsight, this shouldn't have been a shock if we had accepted what the Moon was trying to tell us. Most terrestrial planets, moons, asteroids, and comets show evidence of a severe battering. Saturn's moon Mimas has a crater so big, it indicates the impact probably came close to splitting the moon in half. The near-Earth asteroid Eros not only shows multiple craters but also one large impact site.

Because they don't have solid surfaces, the gas-giant planets don't show any signs of impacts. Still, we know they happen. We had front-row seats in July 1994, when fragments of Comet Shoemaker-Levy 9 smashed into mighty Jupiter. The dark splotches that resulted from these impacts lasted for months, dramatic proof of what can happen when you release an energy equivalent to all the nuclear arsenals on Earth.

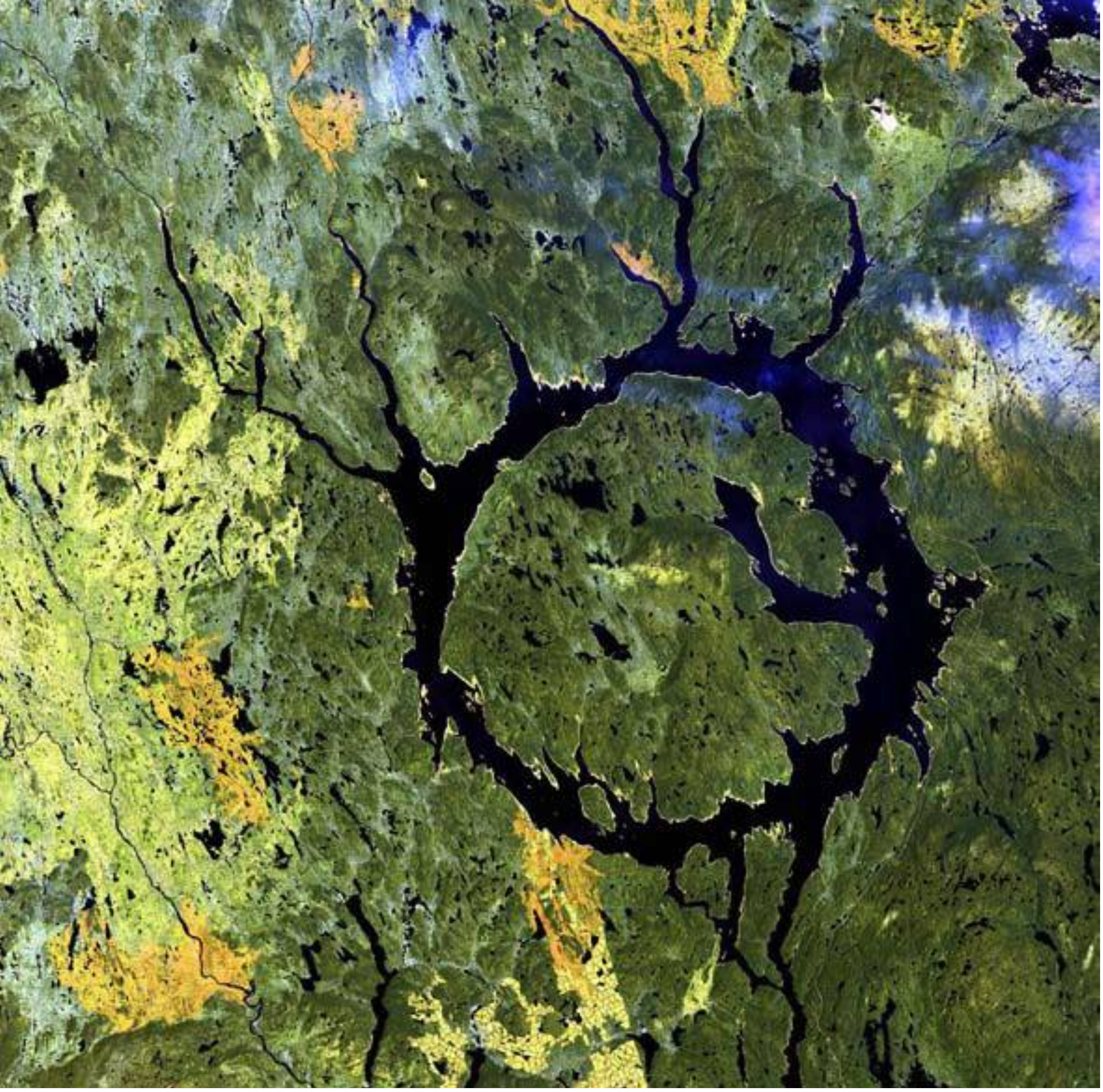
Even with our Moon providing evidence to anyone with a telescope, astronomers and geologists had a hard time believing Earth had suffered from major impacts. Most scientists thought terrestrial craters were volcanic in nature. After all, they have attributes similar to known volcanic features. Some researchers even argued lunar craters could be volcanic.

The debate wasn't resolved until the middle of the 20th century. This was when geologists Eugene Shoemaker and Edward Chao discovered a form of quartz known as coesite at several crater sites. Coesite has a structure that can be formed only quickly and under high pressure. This turned out to be the first unambiguous signature of cosmic impacts.

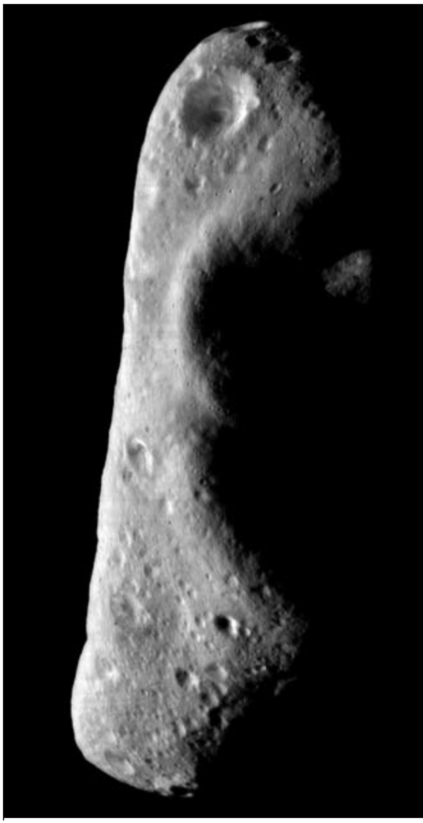
Until a couple of decades ago, impacts by extraterrestrial bodies were considered interesting from a geological perspective, but not of any major consequence. As astronomers and geologists continued to examine the evidence for impacts and bombardment throughout the solar system, however, it became obvious that collisions were a major force shaping the surfaces of these worlds. Eventually, scientists realized evidence of early impacts should be visible on Earth as well.

Impact research gained a lot of momentum in 1980, when physicist Luis Alvarez and his geologist son, Walter, suggested a giant impact caused the extinction of about 50 percent of all living species, including the dinosaurs, approximately 65 million years ago. Apparently, a comet or asteroid some 6 miles (10 kilometers) in diameter struck near the tip of the Yucatán Peninsula and formed a crater called Chicxulub roughly 100 miles (160 km) across. The resulting firestorm sent Earth's climate into a tailspin from which it ultimately recovered — but not before life took a major hit.

Mike Reynolds *is an astronomy professor and the Dean of Mathematics and Science at Florida Community College. He has written several astronomy books, including* Falling Stars: A Guide to Meteors & Meteorites.



LAKE MANICOUAGAN in northern Quebec is the remnant of one of the largest impact features left on Earth. The ring-shape lake surrounds the impact's central uplift. The crater measures about 45 miles (70 km) across and resulted from an impact some 212 million years ago. NASA/USGS



NEAR-EARTH asteroid Eros shows lots of craters, which proves even small objects have been battered since the solar system's beginning. The large, saddle-shape feature partially in shadow is Himeros, a region with fewer craters (suggesting relatively recent resurfacing). NASA/JHU/APL

How to make a crater

Scientists understand the dynamics of crater formation better today. This is attributable in large part to sophisticated computer simulations. Several variables play important roles in what kind of crater an impact will create. The key factors include the size and composition of the impacting body, the speed at which it is traveling, and how its orbit intersects the object being struck. Another critical factor is whether the object being hit has an atmosphere and, if so, how dense it is.

It all comes down to kinetic energy — the impactor's mass and velocity at the moment of impact. (A planet's atmosphere comes into play because it will slow the impactor and may break it up.) In comparing two similar-size impacting bodies, one composed of iron and the other richer in silicate rock or ice, the iron impactor will prove much more devastating.

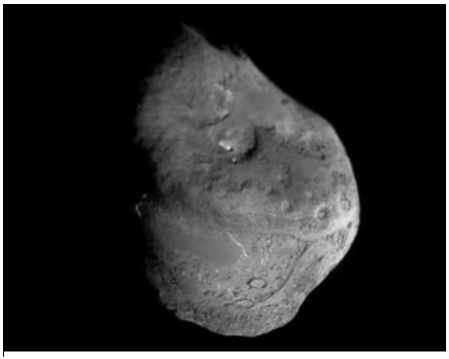
On worlds like the Moon and Mercury, the evidence of impacts has remained mostly undisturbed with the exception of additional impacts. This is obvious to anyone who examines the Moon closely: Craters appear within and on top of other craters.

On Earth, signs of the earliest cratering have been erased. Plate tectonics has resurfaced Earth in the past 2 to 3 billion years, leaving no evidence of the early, heavy bombardment. More recent impact scars have been eroded — in some cases entirely, in many others, enough to make identification difficult. And impacts that occurred in bodies of water — better than a 50-50 proposition — leave little traditional evidence.

So far, scientists have identified about 150 impact craters on Earth, with several new ones joining the list each year. For example, the Tswaing Crater in South Africa was thought to be volcanic in origin just 20 years ago. After several meticulous expeditions, geologists confirmed Tswaing as an impact crater that formed about 220,000 years ago. Tswaing appears similar in size to its more-recent — and more-famous — cousin: Meteor Crater in Arizona.

Craters on Earth

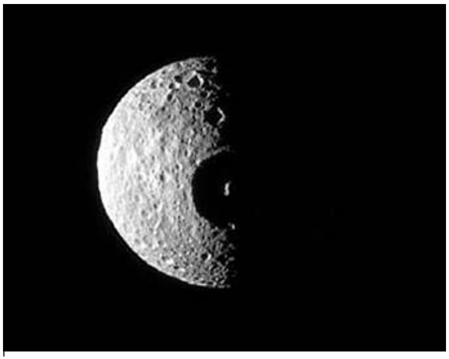
Meteor Crater has to be at the top of the list for any American who wants to see what happens when a big rock hits Earth. This well-preserved crater not only has a classic structure, but it's also on a scale you have to see in person to believe. The crater measures about 4,100 feet (1,250 meters) across and 570 feet (175m) deep. If you converted the crater into a football stadium, it would seat a million people. The impactor responsible for creating Meteor Crater some 50,000 years ago was a classic iron octahedrite about 150 feet (45m) in diameter. Scientists estimate the object was traveling


NASA/JPL/UMD

COMET TEMPEL 1 shows craters can survive even the ravages of gas eruptions. When a comet approaches the Sun, the Sun's heat sublimates ices from the nucleus, and gas spews from the surface.

NASA AND THE HUBBLE COMET TEAM

IMPACTS HAPPEN everywhere in the solar system — even on gas-giant planets. In July 1994, observers watched fragments of Comet Shoemaker-Levy 9 smash into Jupiter's cloud tops, leaving dark spots.


NASA/JPL/SSI

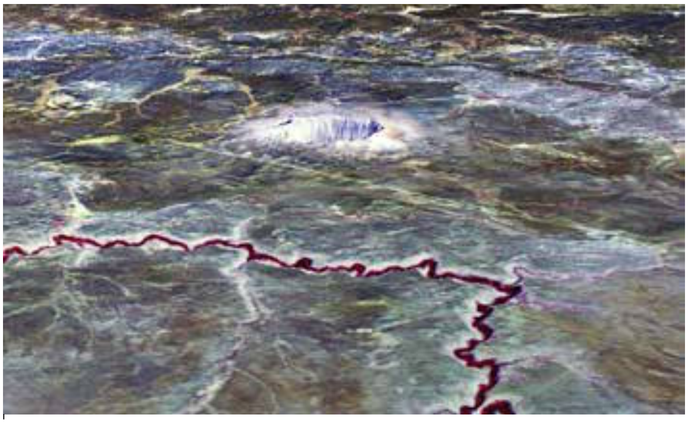
SATURN'S MOON MIMAS came close to breaking up when a massive object hit it. The huge crater, named Herschel, measures 88 miles (140 km) across and sports a prominent central peak.

between 27,000 and 45,000 mph (43,000 and 72,000 km/h). The impact created a pressure that likely exceeded 20,000 times Earth's normal atmospheric pressure.

Some of the earliest crater research took place at Meteor Crater. Even so, most scientists suspected it was volcanic in nature. Native Americans living in the region knew the crater, but it took until 1871 for someone to write about it. It initially was called Franklin's Hole, after the scout for General George Custer who made the report. Local settlers renamed it Coon Butte because they thought it formed volcanically.

The story started to change in the 1890s, when chemist and mineralogist A. E. Foote visited Coon Butte. Foote returned to Philadelphia with a number of meteorites he picked up at the crater. He carefully examined the samples and discovered microscopic diamonds in some of them. He wrote a paper on his research, which caught the attention of Grove Karl Gilbert, the chief geologist of the U.S. Geological Survey (USGS). Still, Gilbert believed the crater was volcanic despite Foote's recovery of numerous iron meteorites from the site.

What happened next changed how scientists looked at Coon Butte. Mining entrepreneur Daniel Moreau Barringer became interested in Coon Butte and spent much of his life and personal wealth exploring it. He searched for the main impactor mass and tried to convince others that Coon Butte formed from an impact and not a volcano.



METEOR CRATER in Arizona is probably the best-known impact feature on Earth. The collision that created this crater occurred 50,000 years ago and left a 4,100-foot-wide (1,250m) and 570-foot-deep (175m) gouge. NASA/GSFC/METI/ERSDAC/JAROS, AND U.S./JAPAN ASTER SCIENCE TEAM

In order to reach what he believed was the main mass, Barringer drilled several holes in the crater. Some of the holes went more than 1,000 feet (300m) deep. Unfortunately, a flooded drill shaft and jammed and broken drills ended his quest. Even though Barringer never found a meteoritic pot of gold at the end of his rainbow, he did recover diamonds, platinum, and iridium in addition to many meteorites. The largest meteorite recovered weighs 1,405 pounds (639 kg). Barringer wrote several papers about his research. Today, the crater also bears the name Barringer Crater, after the man who did so much to understand its secrets.

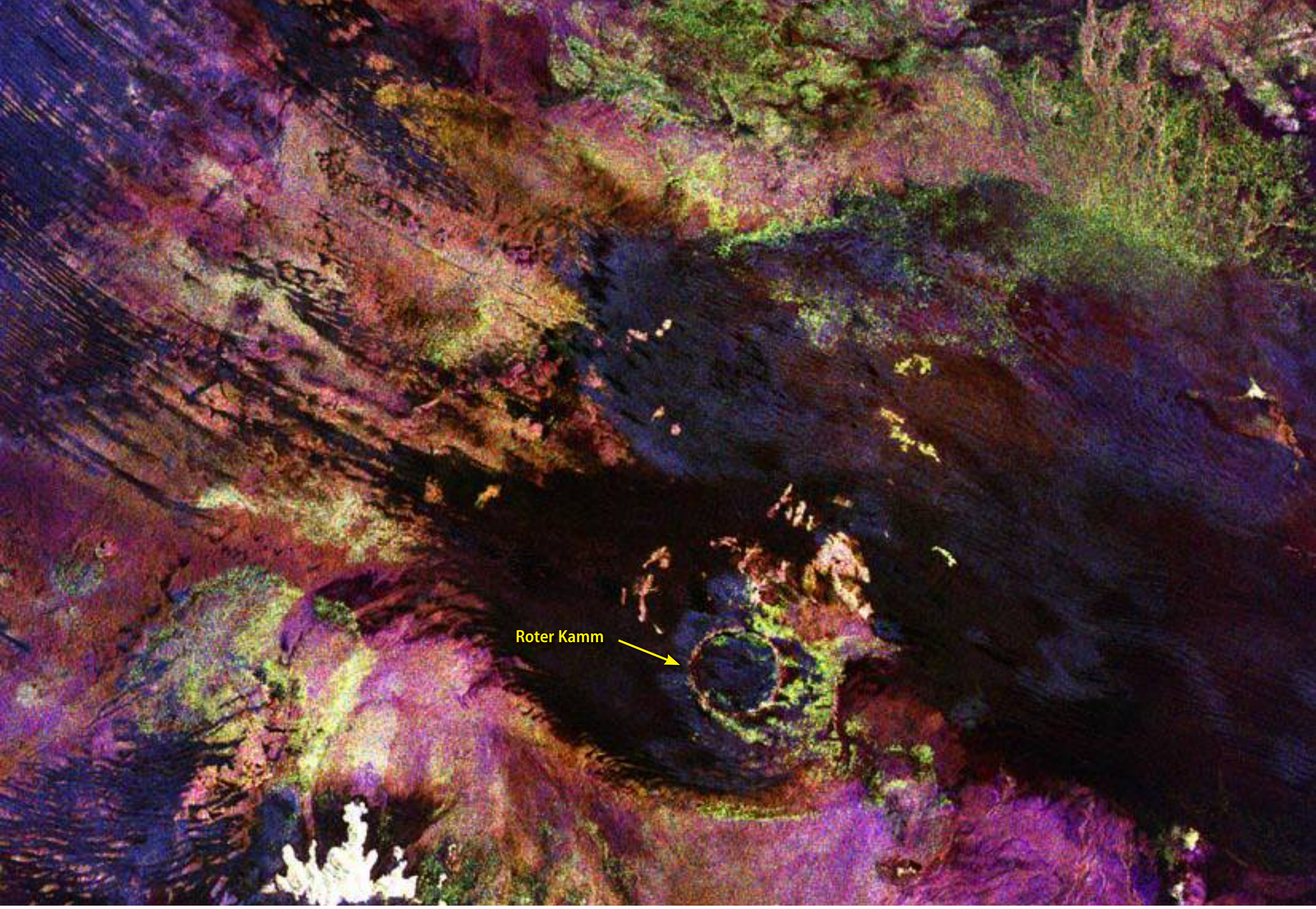
Despite all of the evidence, the argument about the crater's formation wasn't settled for many years. But by 1930, most astronomers and geologists agreed that an asteroid impact created Meteor Crater. With this acceptance came the identification of other terrestrial impact scars, including the Henbury craters in Australia and the Odessa craters in Texas. And in 1955, experiments conducted by F. P. Bundy and his colleagues concluded extreme pressure and temperature were needed to form the diamonds found at Barringer Crater.

One of the biggest contributors to the science of impacts was American geologist Eugene Shoemaker. In the early 1960s, he conceived the Astrogeology Branch within the USGS after researching the mechanics of impacts and cratering. Shoemaker trained the Apollo astronauts in cratering science and lunar geology. He also started a decade-long search for Earth-crossing asteroids and comets. This search led to the codiscovery, with his wife Carolyn and David Levy, of Comet Shoemaker-Levy 9.

More subtle clues

The Odessa craters, located just southwest of Odessa, Texas, are a series of impact structures somewhat different in size and appearance than Meteor Crater. The main crater spans about 550 feet (170m) and exhibits a slightly raised rim. Although the area has been excavated heavily, the three main craters are still recognizable. Barringer's son, D. Moreau Barringer, Jr., demonstrated in 1926 that Odessa most likely resulted from an impact. Over the years,

WEB GEM Calculate the effects of any approaching impactor at the interactive web site www.lpl.arizona.edu/impacteffects.



JUST 5 MILLION YEARS AGO, a meteoroid collided with Earth in southwest Namibia and created the Roter Kamm impact crater. It appears as a bright circle 1.5 miles (2.5 km) across in the lower part of this space-shuttle radar image. NASA/JPL

tons of Odessa meteorites, a coarse iron octahedrite, have been removed from the area.

Astronomers and geologists have put together the puzzle of impact indicators beyond the obvious craters and meteoritic evidence. Impactites — rocks formed from melting during an impact — are one major clue. They were discovered first around the Henbury craters in 1932. Other parts of the story are the specific chemical composition and impactite brecciation: rocks consisting of broken, angular fragments cemented together by a fine-grained matrix. Shatter cones — conical rock fragments with striations — form another terrestrial piece of impact evidence. Shatter cones result from an impact's high pressure and high-velocity shock wave. The locations and orientations of shatter cones also help researchers identify an impact's center. Glasses also can form in the extreme heat and pressure of an impact.

OUR SOLAR system shows the scars of repeated impacts, which led us to comprehend the nature of cosmic pinball.

The large Sudbury feature in northern Ontario, Canada, is an excellent example of an impact with numerous shatter cones and impact glasses. This well-eroded crater, approximately 1.8 billion years old, measures more than 150 miles (240 km) in diameter. The discovery of impact-melt glass called suevite suggests this crater most likely formed when a comet struck Earth. These glasses typically arise where a significant amount of water exists. Although the original terrestrial Sudbury rock did not contain much water, a comet would have brought plenty.

Not all impacts produce craters. Perhaps the best example is the June 30, 1908, event in Tunguska, Siberia. Scientists think a large object — either a stony meteoroid or a comet — entered Earth's atmosphere and exploded above the surface. Although no crater formed, evidence suggests a cosmic event: an initial fireball and the sound of an explosion, the dust created, and trees felled in a radial pattern covering nearly 1,000 square miles.

We often say that looking at the cosmos teaches us a lot about ourselves and our planet. Our solar system shows the scars of repeated impacts, which led us not only to discover similar impact features on Earth, but also to comprehend the nature of cosmic pinball. The scars also help us understand the dynamics of such impacts, and what could happen when the next Meteor Crater or Chicxulub impact event occurs. And it will occur — it's just a matter of when and how big the object will be.

BLAST from

Fifty thousand years ago, a multimegaton impact gouged out Arizona's Meteor Crater. /// BY DAVID A. KRING

In Northern Arizona lies an immense cavity that dwarfs the largest nuclear-explosion crater. Thousands of tons of impacting metal pulverized, melted, and vaporized rock to carve out Meteor Crater. A debris blanket still covers the surrounding landscape.

This asteroid impact site is one of the best-preserved impact sites on Earth, offering an incredible view of nature's destructive power. Although the impact event was too small to cause any global environmental effects, it decimated a local Ice Age ecosystem. If the same impact were to occur in a major city today, it would destroy the city.

The target

Meteor Crater (also known as the Barringer Meteorite Crater) shows a wonderful example of an impact event's geologic effects. The Colorado Plateau — the target — is composed of a simple sequence of well-exposed rock layers deposited millions of years pre-impact. The crater's lower wall is carved from a layer of buff-color Coconino sandstone composed primarily of wind-blown sand. The Coconino sandstone looks like an immense brush has swept it — the surface is scored by what appear to be rake marks. The impact did not produce these marks, however. Rather, they are traces of fossilized dune slopes produced when a huge sand-dune field — similar to the modern Sahara — covered northern Arizona more than 265 million years ago, during the Permian period.

After the Coconino sandstone was deposited, a sea lapped over the landscape from the west. It brought with it a thin layer of pale-yellow Toroweap sandstone and dolomite. The sandy portions of the Toroweap formation represent the fluctuating ancient shoreline of western North America roughly 260 million years ago.

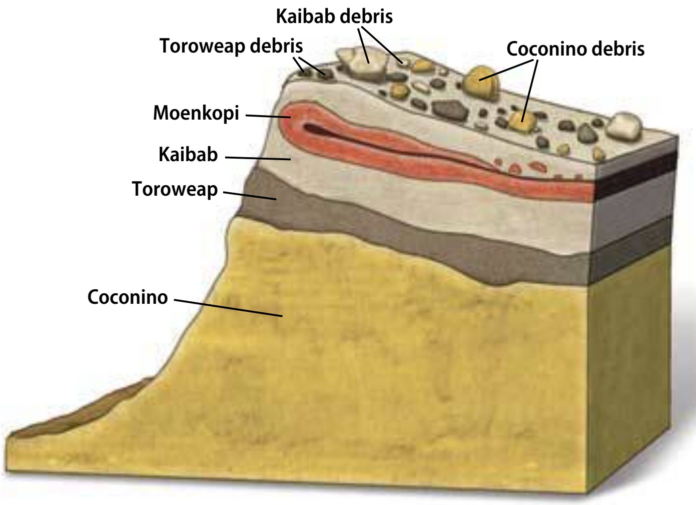
The water soon deepened and covered most of Arizona. It produced a thick, cliff-forming sequence of pale-yellow Kaibab dolomite and sandstone layers that dominate the crater's upper wall. The sea-floor sediments contain fossil shells and preserved burrows of marine organisms that lived and fed in those sediments 250 million years ago.

A striking red Moenkopi siltstone caps the sequence. This siltstone was deposited on a coastal floodplain — similar to modern Louisiana — at the edge of a sea. The layer is covered with ripple marks produced

METEOR CRATER is a well-preserved impact crater in northern Arizona's Colorado Plateau. Thirty-five miles west of the crater, past Canyon Diablo, lies Flagstaff, Arizona, and the surrounding San Francisco Peaks. PETER L. KRESAN

the PAST

Earth's folded layers at Meteor Crater



▲ **UNDER AN IMPACT'S FORCE, rock layers fold back on themselves. At Meteor Crater, the strata overturned at the crater's rim, and the rock pattern was repeated — but inverted.** *ASTRONOMY*: ROEN KELLY, AFTER DAVID A. KRING

◀ **THE UPLIFTED STRATA in Meteor Crater's wall was the key to the crater's impact origin. In addition to the overturned pattern, ejected debris cover the surrounding landscape.** DAVID A. KRING

by water currents over 200 million years ago, during the Triassic period.

These rock layers lay flat before the impact, but the same blast that carved out the crater uplifted the strata in the walls. The walls tilt steeply beneath the crater rim. Under the effects of shock, the strata also behaved more like taffy than rock, and were folded and overturned in the crater rim. Consequently, as you march up the crater walls from layers of Coconino, Toroweap, Kaibab, to Moenkopi, you'll find the sequence repeated, but upside down, in the crater's rim.

In the early 1900s, mining engineer Daniel Moreau Barringer (the crater's namesake) first presented the structure in the crater walls and rim as evidence of the crater's impact origin. In the 1950s and 1960s, geologist Gene Shoemaker strengthened the argument when he compared the structure to that seen at nuclear-blast craters. Today, one of the signatures to distinguish impact craters from volcanic craters is overturned stratigraphy in rims.

The atmosphere's halting force

The asteroid that produced Meteor Crater had to survive a fiery passage through Earth's atmosphere. Smaller asteroids, called meteoroids, are decelerated when they hit the atmosphere. Meteorites, for example, are usually decelerated completely in the atmosphere and then fall simply under the accelerating influence of Earth's gravity.

Because asteroids are so massive, the air they encounter in the atmosphere may be a small fraction of their own mass and, thus, they may be only partially decelerated. The atmosphere least affects the largest asteroids, because the amount of air they encounter is trivial compared to their own masses. In these cases, asteroids hit Earth's surface with most of their cosmic velocity, which averages 38,000 to 45,000 mph (61,000 to 72,000 kilometers/hour).

THE BLAST EXCAVATED 175 million metric tons of rock.

When asteroids and meteoroids plow through the atmosphere at such high velocities, the plunge creates differential forces within the objects. Smaller objects can fragment explosively in the atmosphere, either producing a meteoritic strewn field and/or crater field, or be obliterated completely. For example, the largest known stone meteoroid — the one that fell in Gold Basin, Arizona — hit Earth's atmosphere with 5 to 50 kilotons of kinetic energy and fragmented in the sky. It showered the surface with thousands of rocky remnants. The Odessa iron meteoroid also fragmented, but it still hit the surface with enough energy to produce a 520-feet-wide (160 meters) crater in the midst of several smaller impact craters in Texas.

The asteroid that produced Meteor Crater was large enough to hit Earth's surface with a substantial portion of the rock's cosmic velocity. It produced a crater 0.75 mile (1.2 km) wide and more than 600 feet (180m) deep. Both the size and velocity of the asteroid are important, because these factors determine the explosive energy of the impact.

In 1980, David Roddy of the U.S. Geological Survey and others estimated that the impact energy was equivalent to 15 megatons of TNT, which corresponds to an iron asteroid about 130 feet (40m) in diameter hitting the surface with a speed of 45,000 mph (72,000 km/h). This is about 1,000 times more explosive than the atomic bombs that destroyed Hiroshima and Nagasaki during World War II.

Other estimates for the asteroid's size range from 30 to 160 feet (10 to 50m) and from 1½ to 60 megatons for the blast energy. As of now, the exact energy needed

David A. Kring *is a professor of planetary geology and cosmochemistry at the University of Arizona.*

DAVID A. KRING

THE CRATER’S FLOOR is covered with sediment roughly 100 feet (30 meters) thick at the center. While the sediment accumulated shortly after the blast, wind-blown dust and even vegetation have since made their way into the crater.

to produce Meteor Crater is unknown, although lower values (less than or equal to 20 megatons) are more likely.

Forming a giant bowl

Because the iron asteroid was so massive and moved so quickly, it penetrated 30 feet (10m) to perhaps 160 feet (50m) into the Colorado Plateau and produced a blast slightly below Earth’s surface. Shock waves radiated into the ground and up into the asteroid. The asteroid was largely obliterated, but not before a shock wave reflected from its upper surface. This produced a rarefaction wave — a decrease in density — that then radiated downward into the ground after the initial ground-penetrating shock wave.

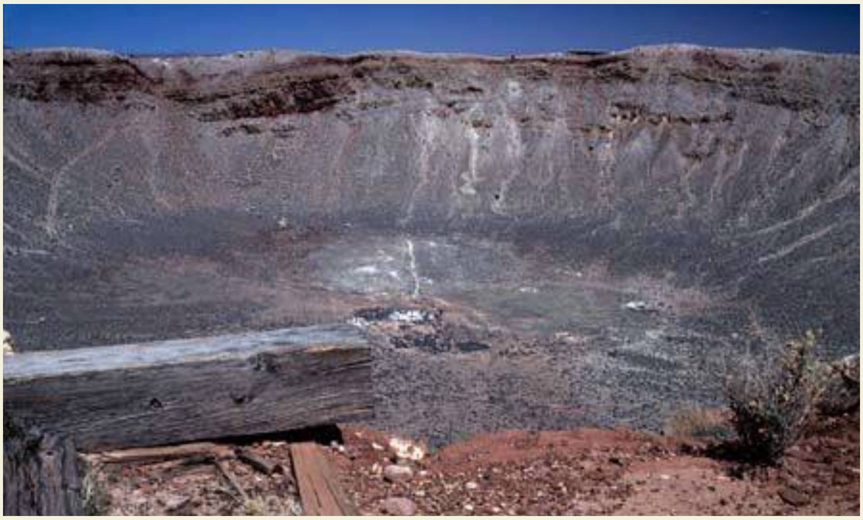
These waves caused rock to flow from the center of the explosion. First traveling downward and then outward and upward, the waves excavated the crater we see today. They generated the uplift seen in the crater walls and created the overturned rim sequence. The blast excavated 175 million metric tons of rock. The result is a bowl-shape cavity defined by an uplifted rim that rises 100 to 200 feet (30 to 60m) above the pre-impact surface. The blast deposited a tremendous amount of rocky rubble around the crater out to distances approximately equivalent to the crater’s diameter. Rocky debris along the crater walls also collapsed toward the crater floor, where debris filled the bottom of the crater’s bowl shape.

Scientists classify Meteor Crater as a simple crater because it has relatively smooth walls and a simple bowl shape. Impact craters can also have complex structures — central peaks, central peak rings, and a series of faulted blocks between the crater center and outer rim — depending on the asteroid angle. Complex craters are also larger than simple craters.

Shocked rock

Severe shock pressures vaporized and melted rocks near the point of impact, but the vast majority of rock affected by the shock wave either ruptured into smaller fragments or transformed into higher-pressure minerals. Quartz crystals in some samples of Coconino sandstone, for example, were converted into the high-pressure minerals coesite and stishovite.

The crystalline structure of quartz in other samples of Coconino sandstone was completely destroyed, transforming the material into a type of glass called lechatelerite. In the most extreme cases, the quartz changed into a bubbly, flowing melt that, when cooled, formed pumice-like glass fragments.



DAVID A. KRING

FROM THE SOUTH RIM looking across the crater, the bowl shape is apparent. You can see the path of debris that slid down the crater wall after the impact.

A CRATER BY ANY OTHER NAME

Meteor Crater is also known as Barringer Meteorite Crater, named after Daniel Moreau Barringer (1860–1929). Barringer spent more than 25 years studying the crater.

Barringer was a mining engineer, and later a geologist, from Philadelphia. He became wealthy after discovering the Commonwealth Silver Mine in Pearce, Arizona. In 1902, Barringer learned of a crater 35 miles (56 kilometers) east of Flagstaff, Arizona. At the time, people thought either a gas explosion or an iron-meteorite impact had created the crater. If the impact theory was true, the iron meteorite may still have been buried near the crater. Barringer and a friend, physicist Benjamin Chew Tilghman, formed the Standard Iron Company and headed out to northern Arizona in search of the iron meteorite.

After 2 years of drilling and searching in and around the crater — including drilling mining shafts at the crater’s center (these shafts are still there today, although closed up) — they found no iron. However, while searching for the meteorite, Barringer and Tilghman scientifically confirmed the crater had, in fact, been created by a meteorite impact, and, in 1906, they presented their findings to the U.S. Geological Survey.

For years, Barringer continued his search for the meteorite. He spent more than $600,000 on the endeavor (which is about $10 million today), nearly bankrupting himself. In 1928, astronomer Forest Moulton analyzed the impact crater and determined the meteorite likely vaporized as a result of the impact; there was no solid chunk of iron sitting below the Colorado Plateau. Just a year later, in November 1929, Barringer died of a heart attack. — *Liz Kruesi*

A 30-TON BLOCK of Kaibab sits on the crater's rim, where the impact's force threw it roughly 50,000 years ago. DAVID A. KRING

METEOR CRATER'S MANY MINERALS

Mineral	Chemical signature	Group	Amount
kamacite	Fe,Ni-alloy	metal	≈ 90 percent
taenite	Fe,Ni-alloy	metal	≤ 4 percent
troilite	FeS	sulfide	≤ 4 percent
daubreelite	$FeCr_2S_4$	sulfide	traces
sphalerite	$(Fe,Zn)S$	sulfide	traces
mackinawite	$(Fe,Ni)S_{0.9}$	sulfide	traces
chalcopyrite	$(Cu,Fe)S$	sulfide	traces
schreibersite	$(Fe,Ni)_3P$	phosphide	traces
cohenite	$(Fe,Ni,Co)_3C$	carbide	traces
haxonite	$(Fe,Ni)_{23}C_6$	carbide	traces
graphite	C	carbon	≤ 4 percent
diamond	C	carbon	traces
lonsdaleite	C	carbon	traces
olivine	$(Mg,Fe)_2SiO_4$	silicate	traces
pyroxene	$(Mg,Fe,Ca)_2Si_2O_6$	silicate	traces
plagioclase	$(Ca,Na)(Si,Al)_4O_8$	silicate	traces
ureyite	$NaCrSi_2O_6$	silicate	traces
krinovite	$NaMg_2Cr_2Si_3O_{10}$	silicate	traces
chromite	$FeCr_2O_4$	oxide	traces
rutile	TiO_2	oxide	traces

Surviving quartz crystals in shocked samples are often cross-cut with a series of microcrystalline fractures and faults. These features, also called planar deformation features, are evidence of shock-metamorphism in impact-cratering events, because other geologic processes cannot produce them. Thus, shocked quartz, in addition to the crater's uplifted and overturned rim, prove Meteor Crater's impact origin.

Surviving fragments

The same shock processes that pulverized the rocks also largely obliterated the asteroid. A few solid fragments survived as iron meteorites, and molten droplets rained down. The iron fragments are called Canyon Diablo meteorites — after the sinuous Canyon Diablo that lies to Meteor Crater's west — and were strewn across the surrounding landscape out to 6 miles (10 km). The largest mass found weighs 1,400 pounds (639 kilograms) and specialists estimate that a total of 30 tons of Canyon Diablo meteorites have been collected over the past 120 years.

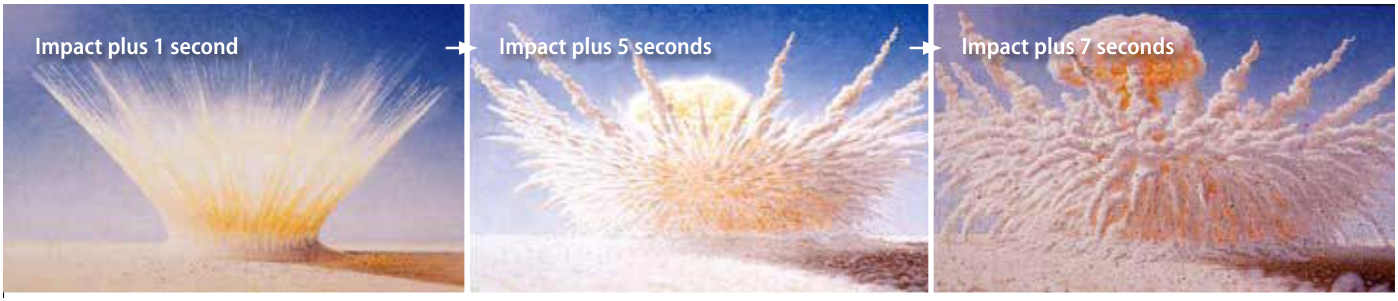
The Meteor Crater impact altered some of the minerals in the asteroid: Shock pressures converted graphite into diamond and lonsdaleite, and heating during the collision recrystallized some of the metallic alloys. Canyon Diablo meteorites also have a fascinating internal crystalline structure called a Widmanstätten pattern. This pattern is generated by an intergrowth of the metallic minerals kamacite and taenite, both of which are iron-nickel alloys that dominate the composition of the meteorites. Small amounts of carbon- and sulfur-bearing minerals are embedded in the metallic pattern, plus trace amounts of several others (see "Meteor Crater's many minerals," at left).

The millimeter to centimeter dimensions of the kamacite crystals in the meteorites indicate the crystals grew while the metal was slowly cooling — on the order of one degree per million years. This slow cooling rate suggests the impacting asteroid was once part of the iron core of a small planet. This means the asteroid that made Meteor Crater was involved in an even larger collision previously, when its parent body was completely disrupted to expose an iron-rich core.

Young, in impact years

The pristine state of Meteor Crater suggests it is a relatively young impact crater. It is much better preserved, for example, than the Tswaing Crater in South Africa, which is similar in size but formed 220,000 years ago. Determining the age of an impact crater is often difficult, but, fortunately, the Meteor Crater event reset several radiometric clocks. Each clock independently indicates the crater was produced roughly 50,000 years ago.

The first clock relies on a technique called thermoluminescence, which is a measure of the crystalline damage caused by the decay of naturally occurring radioactive elements in rocks. In this case, Steve Sutton of Argonne National Laboratory outside



THE IMPACT'S EFFECTS were felt within seconds. This series shows rock and dust being hurled away from ground zero. Any animals within 2 miles (3 km) of the impact site would have been killed instantly, and those out to 10 miles (16 km) seriously injured.

ILLUSTRATIONS BY DON DAVIS COURTESY OF METEOR CRATER, NORTHERN ARIZONA, USA

Chicago studied the damage caused by uranium, thorium, potassium, and rubidium in samples of Kaibab and Coconino debris. He discovered the impact's shock heating reset this clock to zero and that the samples have accumulated about 49,000 years of damage since the impact.

Kuni Nishiizumi of the University of California at Berkeley, Fred Phillips of New Mexico Tech, and others used different types of radiometric clocks, although they too measured the amount of time excavated rocks were exposed at Earth's surface. They determined that cosmic rays produced chlorine-36, beryllium-10, and aluminum-26 in blocks of Kaibab debris after the impact event, and the accumulated amount of these isotopes is consistent with a 49,000-year age for the crater.

Destructive to the environment

Given the crater's age, the impact occurred during the Ice Age. The environment then was different from today's arid landscape. From fossil pollen and animal bones and scat found in the region, a juniper-piñon woodland covered a gently rolling countryside. Large mammals — like mammoths, mastodons, giant ground sloths, bison, camels, tapirs, and horses — may have lived in the vicinity of the multimegaton blast.

The damage the impact inflicted was similar to a nuclear-bomb blast, but without ionizing radiation damage. The asteroid, bedrock, and any flora and fauna at ground zero were vaporized. The explosive shock wave produced winds in excess of 620 mph (1,000 km/h) within about 2 miles (3 km) of the impact. These winds stripped away any grass near the crater and flattened any juniper and piñon trees out to approximately 9 miles (14 km). Ejected and overturned bedrock buried any surviving organisms out to about 1.2 miles (2 km).

Several other impact effects severely hurt animals in the area. Dramatic differences in animals' internal pressure versus the external pressure exerted by the shock wave caused swelling and internal bleeding. Animals near the impact site would have been thrown short distances by the air blast.

A hot fireball created by the blast may have also burned vegetation and animals out to a similar distance. Vegetation over an area of 300 square miles (800 square km) was destroyed, and another 80 square miles (200 square km) could have been damaged. Animals within 2 miles (3 km) of the impact site were probably killed, with maiming injuries extending out to distances of about 10 miles (16 km).

IMPACT BRECCIA — fused together rock fragments — lie scattered throughout the crater. DAVID A. KRING

Although severe, these effects were confined to the immediate region and did not cause extinctions. In fact, the newly formed bowl-shaped depression soon filled with water, providing a lake habitat for aquatic plants and animals. The area probably recolonized completely within 100 years.

Lake sediments deposited as the ecosystem evolved. About 10,000 years ago, the region became arid, and the lake developed into a playa — a dry lake basin. The sediments partially filled the crater, so it is now about 100 feet (30m) shallower than it was originally. The lake sediments are exquisitely preserved and, if recovered, may provide the best climate record for the past 50,000 years on the entire Colorado Plateau.

Impact hazards

Although the effects of the Meteor Crater impact were not as severe as those caused by the Chicxulub impact (which caused dinosaurs' extinction) at the Cretaceous-Tertiary (K-T) mass-extinction boundary, it is another example of how impact cratering affects both Earth's geology and biology. Our planet is constantly pummeled by planetary debris. Fortunately, large asteroids hit far less frequently than small asteroids.

A Chicxulub-size event occurs, on average, once every 100 million years. A Meteor Crater-size event occurs about once per 1,500 to 2,000 years, although there is still considerable uncertainty in these numbers. A cratering event like that of Meteor Crater could destroy a city and its residents from the initial impact and by causing the collapse of buildings and other urban infrastructure.

Because the Meteor Crater asteroid was near the threshold size for cratering (versus breaking apart in the atmosphere), most similar-size objects — mostly stone asteroids — detonate before reaching the ground and produce kiloton to megaton explosions in the atmosphere instead. These impacts, however, can still cause severe damage on the ground. We learned during the Cold War that explosions at an optimum blast height in the atmosphere can cause even more damage than a surface explosion of a similar size. In either case, a multimegaton impact event is something best witnessed from afar — whether in distance or time.

We can be glad that 50,000 years separate us from the Meteor Crater impact.

ONLINE EXTRA Learn about mass-extinction impacts at www.astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

AUGUST 06

Long, mild nights and fast-moving meteors make August the perfect month for soaking up a sky full of stars during camping trips and star parties.

Oscar time for the sky

Swift "shooting stars" make their annual return in mid-August. The Perseid meteor shower peaks the night of August 12/13, when you should see some 30 meteors per hour. ☾ Through the ages, Comet 109P/Swift-Tuttle has spread motes of dust along its orbit as it passed through the inner solar system. When Earth sweeps through this band every year in mid-August, the dust burns up from friction with the upper atmosphere. The entry speed clocks in at a blistering 37 miles per second, giving rise to the Perseids' bright flashes.

A PERSEID METEOR **streaks across the sky at 37 miles per second, flaring as it disintegrates in Earth's atmosphere.** GRAHAME PARKIN

Meteor rates should be lower than usual this year because bright moonlight will hide the fainter streaks. The Perseids run around half-strength a night on either side of maximum, so watch then if the weather looks bad for the peak.

Meteor watching is a great family or group activity because you don't need any optical equipment. And it's easy to stay enthusiastic during a dry spell when someone else sights a shooting star and lets out an audible "ooh." Bring along blankets, sleeping bags, and hot chocolate because August nights can seem cool after a hot day. See "Party with the Perseids!" on page 76 for more meteor-observing details.

In the deepening twilight this month, a bright beacon shines fairly low in the southwest. This is the king of planets, giant Jupiter. Despite lying some 500 million miles from Earth, its huge girth reflects a lot of sunlight toward us, enough to outshine the brightest stars in the sky.

Less than 4 years from now, we'll reach the 400th anniversary of Galileo's discovery of Jupiter's four biggest moons. The smallest telescope will reveal these tiny dots next to Jupiter's bright disk, and even steadily held binoculars makes this feat possible.

What's a star party? It's when dozens or hundreds of amateur astronomers get together far from city lights to appreciate the wonders of our universe. If you've been trying to figure out which telescope to buy, this is a great spot to see many in action and talk to owners about the equipment's pros and cons. Just ask before you touch. Check out "Coming events" on page 94 to find the nearest star party, or ask at your local planetarium or science center.

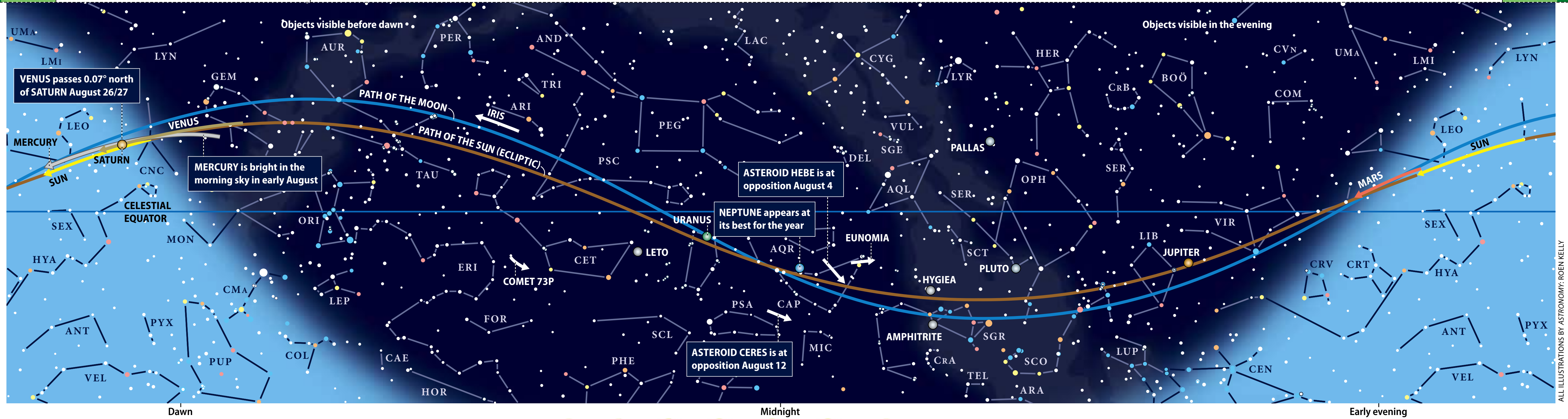
Out in the country darkness, you'll notice a wide band of light crossing the sky. Called the Milky Way because of its appearance, this soft-white glow gave its name to our galaxy, home to hundreds of billions of suns. The glow comes from the combined light of these stars inhabiting the galaxy's spiral arms nearest to Earth. Toward the southern part of the sky, the glow gets brighter and broader — this is our galaxy's hub.

After midnight, once Earth has turned the sky westward, the constellation Aquarius stands where Jupiter was at dusk. A different gas-giant planet, Uranus, now lies here. Its smaller size and greater distance leave it glowing much fainter than Jupiter. At magnitude 5.7, Uranus is just bright enough to see without optical aid from a dark site. From a suburban backyard, you can track it easily with binoculars. While you're at it, take the opportunity to track a couple of nearby asteroids.

The monthly cycle of our Moon brings it below Jupiter August 1 and again on the 29th. Notice how the Moon's phase has thinned, indirect evidence for Earth's movement around the Sun. If you're an early riser, or on summer holiday, make an effort to look east an hour before sunrise. The Last Quarter Moon approaches the beautiful Pleiades star cluster (M45) August 16. Meanwhile, close to the horizon, brilliant Venus guides the way to Mercury. Late in the month, Venus skims just north of ringed Saturn.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



Objects visible before dawn

Objects visible in the evening

VENUS passes 0.07° north of SATURN August 26/27

MERCURY is bright in the morning sky in early August

ASTEROID HEBE is at opposition August 4

NEPTUNE appears at its best for the year

ASTEROID CERES is at opposition August 12

UMa
LMi
LYN
GEM
AUR
PER
AND
TRI
ARI
PATH OF THE MOON
IRIS
PATH OF THE SUN (ECLIPTIC)
LEO
MERCURY
VENUS
SATURN
SUN
CNC
TAU
CELESTIAL EQUATOR
SEX
MON
ORI
HYA
CMa
LEP
ERI
COMET 73P
CET
LETO
PSC
PEG
LAC
CYG
LYR
VUL
SGE
DEL
PALLAS
HER
CrB
BOÖ
CVn
UMa
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LEO
SUN
MARS
AQL
SER
OPH
SER
URANUS
EUNOMIA
AQR
SCT
PLUTO
HYGIEA
LIB
JUPITER
VIR
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PSA
CAP
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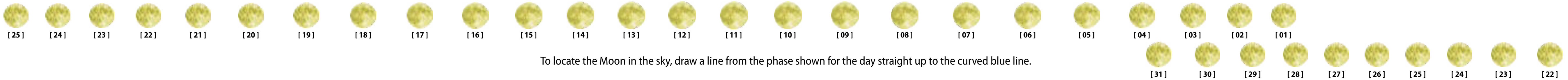
Dawn
Midnight
Early evening



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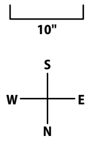
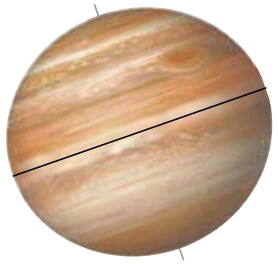
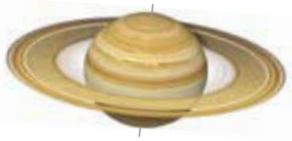
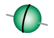
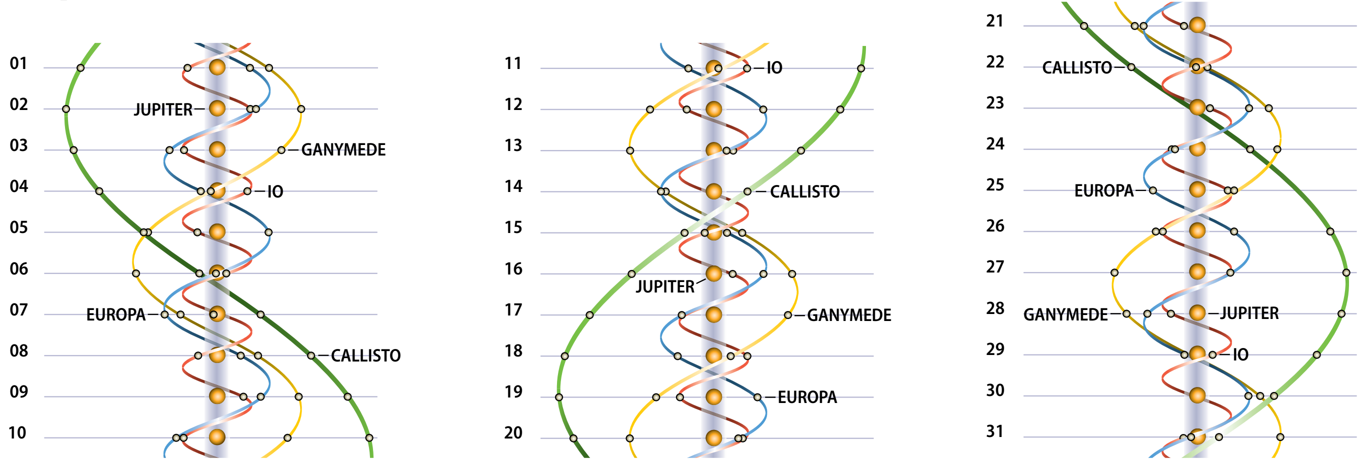
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

ALL ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

PLANETS 	MERCURY	MERCURY	VENUS	MARS	 JUPITER	 SATURN	 URANUS	NEPTUNE	PLUTO
Date	August 1	August 15	August 15	August 15	August 15	August 31	August 15	August 15	August 15
Magnitude	—	–0.9	–3.7	1.8	–2.0	0.5	5.7	7.8	13.9
Angular size	9.0"	6.1"	10.5"	3.7"	35.9"	16.5"	3.7"	2.4"	0.1"
Illumination	21%	70%	94%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.749	1.095	1.591	2.543	5.498	10.096	19.137	29.043	30.609
Distance (AU) from Sun	0.375	0.310	0.719	1.654	5.400	9.152	20.083	30.053	31.156
Right ascension (2000.0)	7h30.6m	8h32.3m	8h19.7m	11h04.2m	14h36.1m	9h21.8m	23h00.4m	21h22.9m	17h35.7m
Declination (2000.0)	18°38'	19°13'	20°03'	6°59'	–14°15'	16°19'	–7°15'	–15°34'	–15°52'

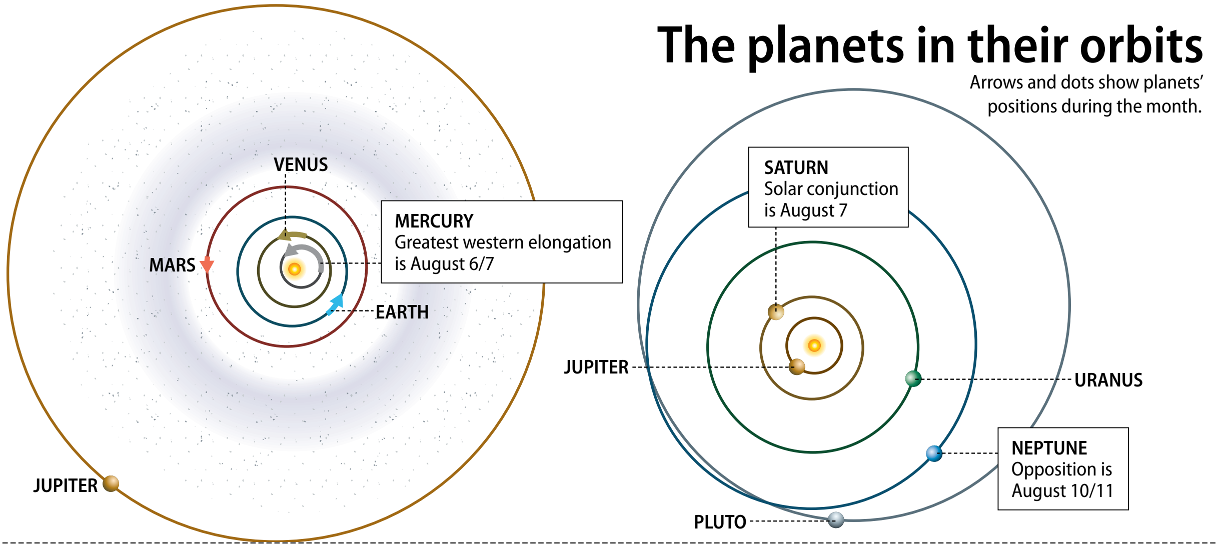
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on date shown. South is at top to match the view through a telescope.



The planets in their orbits

Arrows and dots show planets' positions during the month.



MERCURY
Greatest western elongation is August 6/7

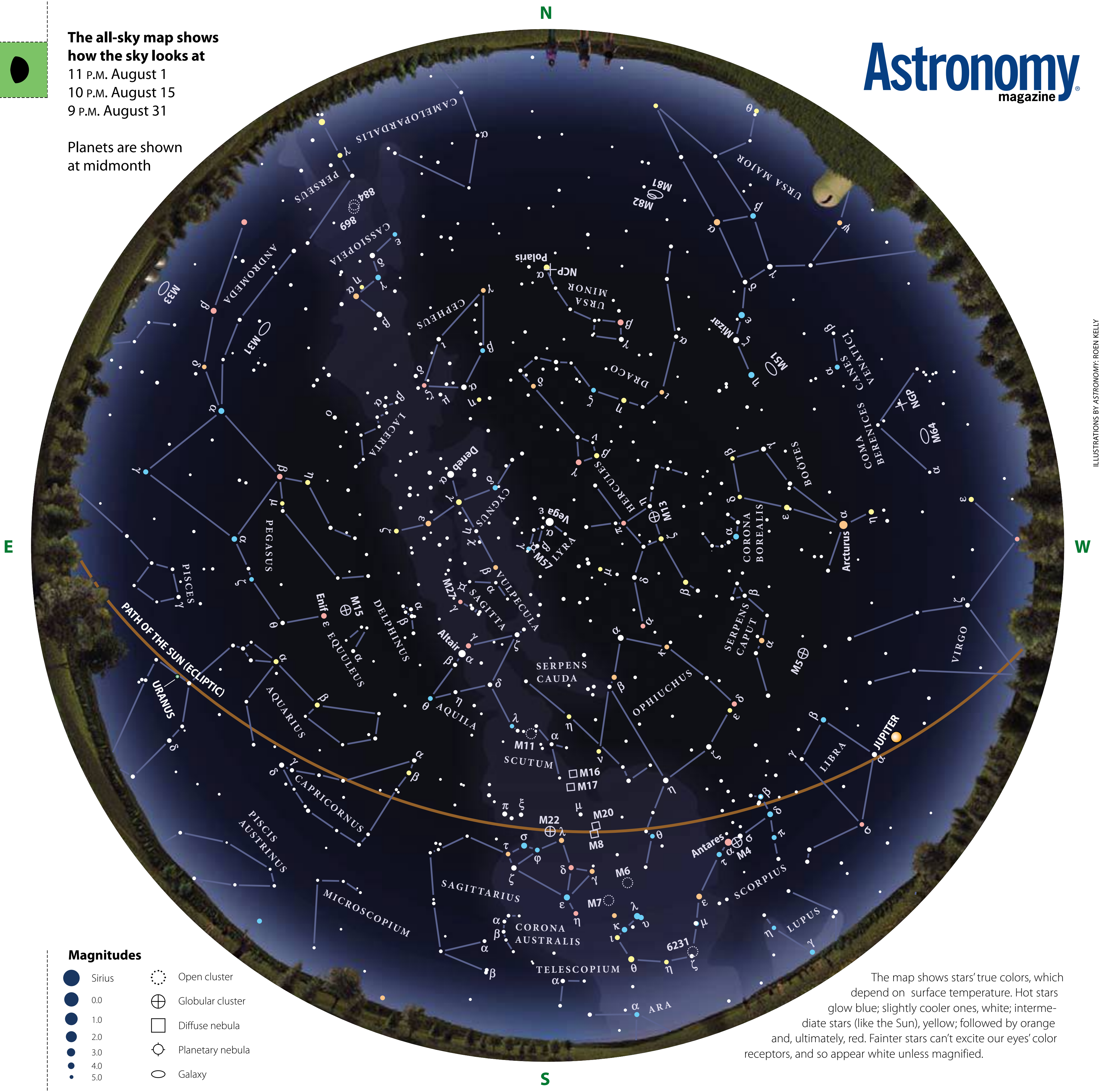
SATURN
Solar conjunction is August 7

NEPTUNE
Opposition is August 10/11

VENUS
MARS
EARTH
JUPITER
JUPITER
URANUS
PLUTO

The all-sky map shows how the sky looks at
11 P.M. August 1
10 P.M. August 15
9 P.M. August 31

Planets are shown at midmonth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E
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CAMELOPARDALIS
PERSEUS
884
869
CASSIOPEIA
ANDROMEDA
M33
M31
URSA MAJOR
M81
M82
Polaris
NCP
URSA MINOR
CEPHEUS
Mizar
M51
CANES VENATICI
DRACO
COMA BERENICES
NGP
M64
LACERTA
Deneb
CYGNUS
Vega
LYRA
M57
HERCULES
M13
BOÖTES
CORONA BOREALIS
Arcturus
PEGASUS
PISCES
Enif
M15
DELPHINUS
EQUULEUS
M27
SAGITTA
VULPECULA
Altair
AQUILA
SERPENS CAUDA
OPHIUCHUS
SERPENS CAPUT
M5
VIRGO
PATH OF THE SUN (ECLIPTIC)
URANUS
AQUARIUS
CAPRICORNUS
M11
SCUTUM
M16
M17
LIBRA
JUPITER
M22
M20
M8
Antares
M4
SCORPIUS
PISCIS AUSTRINUS
MICROSCOPIUM
SAGITTARIUS
M6
M7
CORONA AUSTRALIS
TELESCOPIUM
6231
LUPUS
ARA

The map shows stars' true colors, which depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Magnitudes

●	Sirius
●	0.0
●	1.0
●	2.0
•	3.0
•	4.0
·	5.0

◌	Open cluster
⊕	Globular cluster
☐	Diffuse nebula
⌖	Planetary nebula
⬭	Galaxy

This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Astronomy magazine

august 06

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
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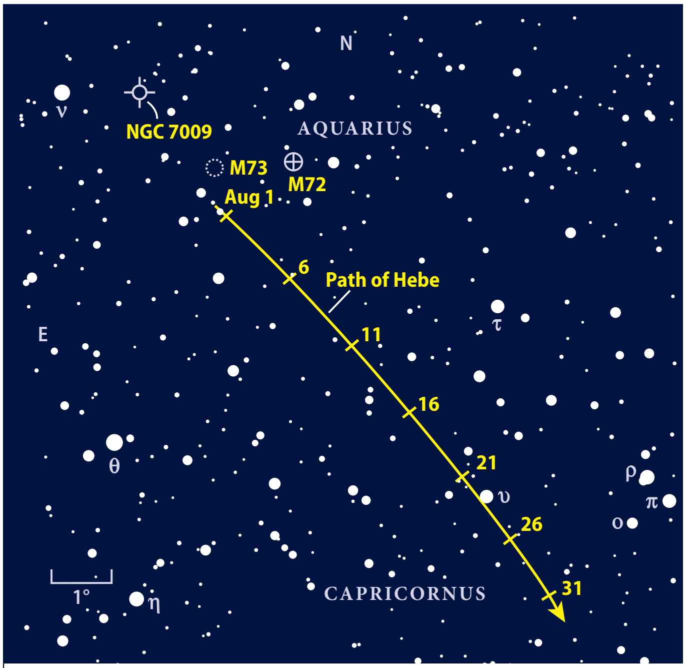
ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

02	First Quarter Moon occurs at 4:46 A.M. EDT
	The Moon passes 5° south of Jupiter, 8 A.M. EDT
04	The Moon passes 0.4° south of Antares, 2 P.M. EDT
	Asteroid Hebe is at opposition, 8 P.M. EDT
06	Mercury is at greatest western elongation (19°), 9 P.M. EDT
07	Saturn is in conjunction with the Sun, 8 A.M. EDT
09	Full Moon occurs at 6:54 A.M. EDT
10	The Moon is at perigee (223,538 miles from Earth), 2:26 P.M. EDT
11	Neptune is at opposition, 1 A.M. EDT
12	Asteroid Ceres is at opposition, 11 A.M. EDT
12	Perseid meteor shower peaks
15	Last Quarter Moon occurs at 9:51 P.M. EDT
21	The Moon passes 3° north of Venus, 11 P.M. EDT
23	New Moon occurs at 3:10 P.M. EDT
25	The Moon passes 0.6° south of Mars, 10 A.M. EDT
	The Moon is at apogee (252,444 miles from Earth), 9:22 P.M. EDT
26	Venus passes 0.07° north of Saturn, 7 P.M. EDT
28	The Moon passes 0.5° south of Spica, 4 A.M. EDT
29	The Moon passes 5° south of Jupiter, 9 P.M. EDT
31	First Quarter Moon occurs at 6:57 P.M. EDT
	The Moon passes 0.5° south of Antares, 10 P.M. EDT

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

THE DEEP SKY

Aquarius the Water-bearer harbors a beautiful planetary nebula that looks surprisingly like the planet Saturn. This month, interloping asteroid 6 Hebe will draw your attention to the right region.



SOUTHWESTERN AQUARIUS BOASTS two Messier objects, but its deep-sky highlight is NGC 7009.

ASTRONOMY: ROEN KELLY

Nature imitates nature

It's amazing how the spiral pattern of a distant galaxy can resemble an earthly hurricane, despite the huge difference in scale. In another cosmic coincidence, a large gas cloud more than a light-year across looks like a ghostly version of the beautiful planet Saturn when its rings appear close to edge-on.

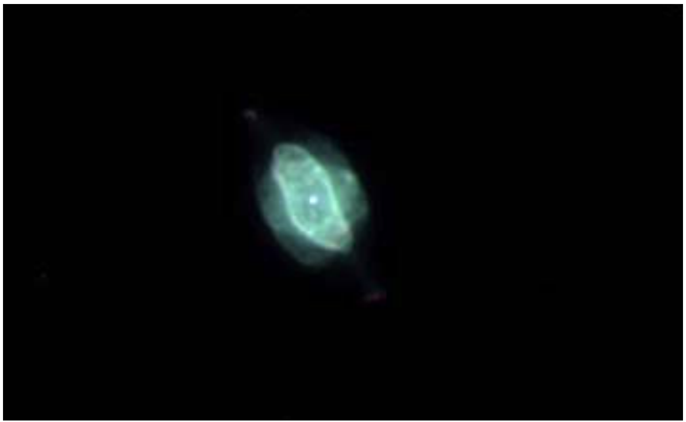
Located in southwestern Aquarius roughly 3,000 light-years away, the Saturn Nebula (NGC 7009) glows with the light of an 8th-magnitude star. Through a 4-inch telescope at low power, the nebula looks like a slightly out-of-focus star, a little softer than its neighboring pinpoints. Bump up the power to 150x to see the fairly well-defined disk. With an 8-inch, you should notice some blue-green color when you look straight at it. In low-light conditions, a sideways glance (averted vision) is black and white. Only central vision detects color.

Just visible in a 12-inch, and spectacular in a big "star party" scope, are the two straight extensions that inspired Lord Rosse to name it the Saturn Nebula in the mid-1800s. Because of this planetary nebula's high surface brightness, it can withstand a lot of power and begins to look like a Hubble image without the color. If a big-scope owner is willing to show it off, you will even see the bumps on each extension, which are called "ansae."

A pair of Messiers

"Quaint" pretty much sums up the mismatched pair of deep-sky objects cataloged as M72 and M73. M72 is a distant globular cluster, while M73 is classified as an asterism — it's nothing more than a group of four modest stars.

Perched in the halo of our galaxy some 55,000 light-years away is M72. Its 200,000 stars put out enough combined light to show up in a small telescope. The great distance reduces it to a fuzzy cotton ball glowing at magnitude 9.2. A 6-inch scope at high power under a dark sky will pick up a few of the cluster's red giant stars, giving the object an overall granulated appearance.



THE SATURN NEBULA (NGC 7009) **bears an uncanny resemblance to the gas-giant planet.** BRAD EHRHORN/ADAM BLOCK/NOAO/AURA/NSF

The main reason observers hunt down M73 is to complete their Messier lists. Through a small, inferior telescope in the 1780s, comet-hunter Charles Messier thought this star group contained some nebulosity. Modern measurements reveal these stars lie at different distances and travel in different directions, so they are unrelated.

A rock at max

It's not often we find a bright asteroid in the vicinity of a Messier object, so we'll let 6 Hebe point the way to this month's deep-sky objects. At magnitude 7.9, Hebe will be easy to locate less than 1° south of M73 August 1. It then heads south into Capricornus. From under dark skies, Hebe is within reach of binoculars, but a small scope from a suburban backyard can pick it up. Can you see which "star" moves from one night to the next?

Martin Ratcliffe is the former president of the International Planetarium Society. ***Alister Ling*** *is a meteorologist for Environment Canada.*

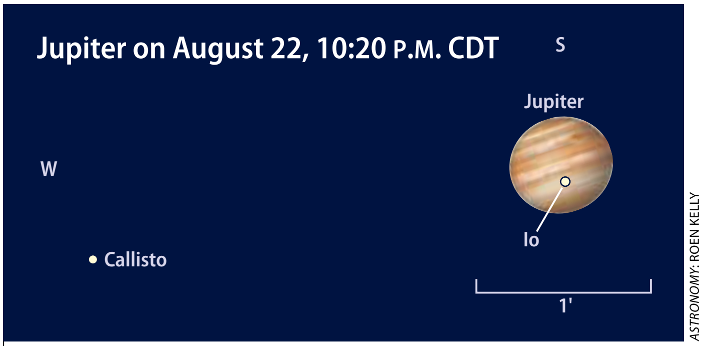
THE PLANETS

Giant Jupiter dominates August's evening sky, while early morning observers can see Venus and Saturn pass just 1 Moon-width apart.

Head out at dusk if you want a final glimpse of **Mars** before winter. The Red Planet appears as a modest star low in the western sky about 30 minutes after sunset. It shines at magnitude 1.8, similar to the brightest stars in the Big Dipper. Mars becomes harder to spot as August progresses, and by month's end, it's lost in the twilight. Your last good chance to spy the planet occurs August 25, when a 2-day-old crescent Moon lies 5° to the left and slightly above the planet.

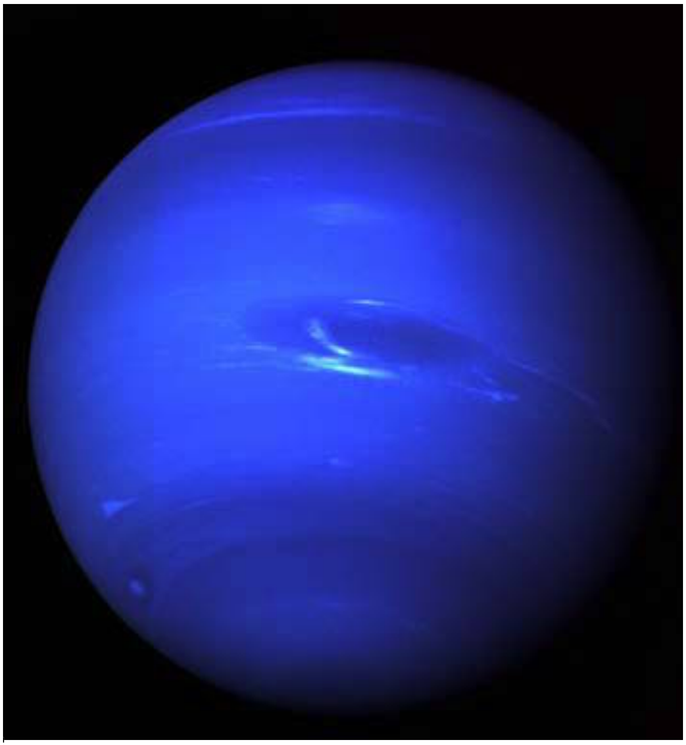
Higher in the southwest at dusk, brilliant **Jupiter** reigns as the brightest "star" in the evening sky. The planet shines at magnitude –2.0; only the Moon is brighter. You can compare the two twice this month; the Moon passes 5° south of the planet August 1 and 29. At their first meeting, the Moon appears half-lit. By the second go-round, the Moon shows a distinctly crescent phase.

Jupiter currently lies among the faint background stars of Libra the Scales. Watch the planet draw closer to 3rd-magnitude Zubenelgenubi (Alpha [α] Librae) throughout the month. The gap shrinks from 5° to 2° thanks to Jupiter's orbital motion tempered slightly by Earth's own movement around the Sun.



ASTRONOMY: ROEN KELLY

JUPITER'S GALILEAN MOONS number four, and it's a rare occurrence when only one of this quartet is visible.



NEPTUNE APPEARS BLUE-GRAY and featureless to earthbound observers, a far cry from this view Voyager 2 got. NASA/JPL

Jupiter's visible "surface" — actually the upper deck of its cloud belts — changes hourly. It makes a fine target for telescopes both big and small. The planet's disk spans 37" August 1 and shrinks slightly during the month as Jupiter's distance from Earth increases. Observers can get up to 2 hours of observing time each night before Jupiter sinks too low. It sets around midnight August 1, and 2 hours earlier by month's end.

Jupiter's four major moons — Io, Europa, Ganymede, and Callisto — continue their perennial waltz back and forth, in front and behind, the planet. The positions change from night to night and, in the case of the two inner moons, the motion can be seen hourly.

You'll have little trouble seeing Jupiter's shadow eclipse the moons this month because the planet lies 90° east of the Sun (a point called quadrature). This places Jupiter's shadow as far from the planet's disk as it can get from our earthly perspective, so the gleaming planet doesn't interfere much.

Ganymede provides the best views because it enters Jupiter's shadow well east of the planet's disk. Io and Europa lie too close to Jupiter for us to observe an eclipse's beginning. (These moons enter the planet's shadow while still hidden behind the disk.) And Callisto orbits far enough from Jupiter it completely misses the shadow.

Occasionally, three jovian moons simultaneously undergo either an eclipse or transit in front of Jupiter, leaving only one moon visible. Three such times occur this month, one visible from Europe and two from North America. For the European event, watch between 1:17 A.M. and 2:06 A.M. British Summer Time August 16. Europa and Ganymede will then be in eclipse, while Io is in transit. This leaves only Callisto visible. North Americans can witness two events just a week apart. Only Callisto will be on view from 11:14 P.M. to 12:23 A.M. EDT the night of August 22/23, and again between 12:11 A.M. and 12:31 A.M. EDT August 30.

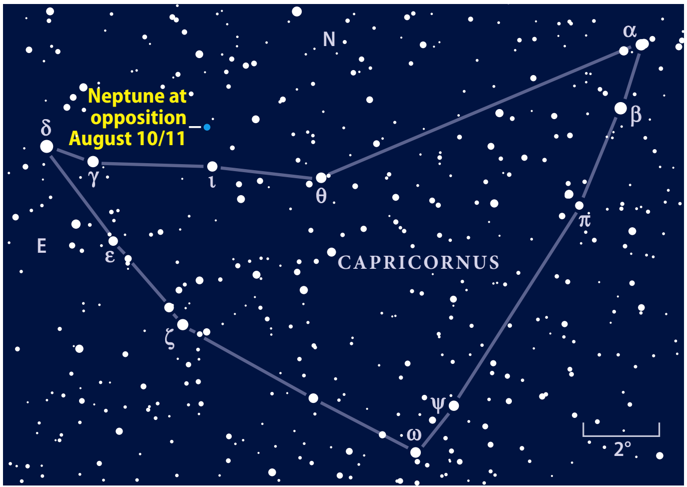
Pluto stands 0.5° southwest of the 3.5-magnitude star Xi (ξ) Serpentis August 1. This distance increases to 0.8° by month's end. This proximity greatly eases the task of finding Pluto's field. Still, seeing the 14th-magnitude planet is a supreme challenge for visual observers with an 8-inch scope. The challenge becomes more manageable with a larger light-collecting area. And the task becomes easier still with a good digital or CCD camera. Pluto lies 2.8 billion miles from Earth.

August offers the best viewing of the year for **Neptune**. The planet reaches opposition August 10/11, when it lies due south around local midnight and remains visible all night. Glowing at magnitude 7.8, Neptune shows up nicely in 7x50 binoculars. You can find it 1.2° north of Iota (ι) Capricorni. A telescope will show Neptune's blue-gray disk, which measures just 2.4" across. Despite a diameter 4 times Earth's, it appears small because it lies 2.7 billion miles away.

Neptune's cousin, **Uranus**, is a month away from opposition and so lies farther east, within the borders of the constellation Aquarius. A dark-sky location offers observers the chance to spot Uranus, which glows at magnitude 5.7, without any optical aid. To attempt this feat, observe when Uranus lies near its highest point in the south (a little past local midnight) on a night with excellent atmospheric transparency, such as you'll find after a summer storm blows through.

During August's first week, Uranus lies close to a slightly fainter star, 81 Aquarii (magnitude 6.2). The seventh planet passes less than 0.1° south of the star August 6. On the 10/11th, the planet lies less than 1° north of the waning gibbous Moon. Uranus continues to move westward all month, ending August 1.3° due east of Lambda (λ) Aquarii.

Take a peek at Uranus through a telescope to see its 3.7"-diameter disk. Color perception is subjective, depending on each person's retinas, but most observers detect a blue-green hue. Compare its color with Neptune's duller hue.



NEPTUNE reaches opposition this month, when the planet glows brightest and remains visible all night. *ASTRONOMY*: ROEN KELLY

A trio of planetary conjunctions or near conjunctions occurs in August's morning sky, along with one of the best morning views of Mercury in 2006. Venus has spectacular meetings with both Mercury and Saturn; Mercury and Saturn also undergo a conjunction.

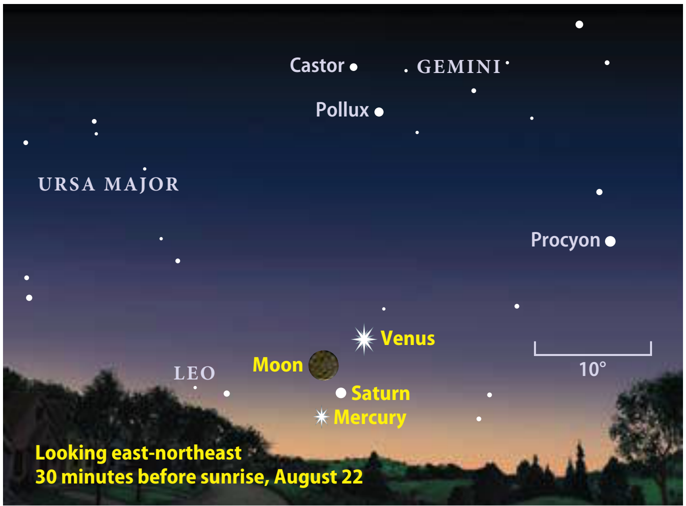
Mercury reaches its greatest elongation west of the Sun August 6/7. On that date, the planet appears 10° above the brightening eastern horizon 30 minutes before sunrise. At the same time, **Venus** gleams brilliantly just 3° away. Mercury then shines at magnitude 0.0 and Venus appears 30 times brighter, at magnitude –3.7.

Three days later, Venus and Mercury come within 2° of each other, as they together traverse the constellation Cancer the Crab. On August 16, Mercury passes 1° south of the Beehive star cluster (M44), followed by Venus August 19. Twilight will hinder your view of the Beehive.

As these planets move east relative to the stars, **Saturn** rises to meet them. Although Saturn lies behind the Sun from our perspective August 7, it reappears in the morning sky by August's third week. On the 21st, less than 1° separates Mercury and Saturn. By then, Mercury has brightened to magnitude –1.5, while Saturn appears 6 times fainter, at magnitude 0.4.

The much brighter Venus stands 6° above the pair, creating an impressive planetary trio. That same morning, a slender crescent Moon adds to the scene when it passes 8° above Venus. On the 22nd, an even thinner crescent stands 3° to Saturn's upper left, with Mercury 2° to Saturn's lower left. All four objects lie within a 7.5°-wide circle.

Mercury drops lower each morning thereafter, eventually disappearing in the twilight glow. Meanwhile, Saturn climbs higher, where it meets Venus August 26. The pair then lies 0.5° apart and will be visible in the same low-power telescopic field of view.



ASTRONOMY: ROEN KELLY

A PLANETARY TRIO awaits early risers in late August, when Mercury, Venus, and Saturn congregate.

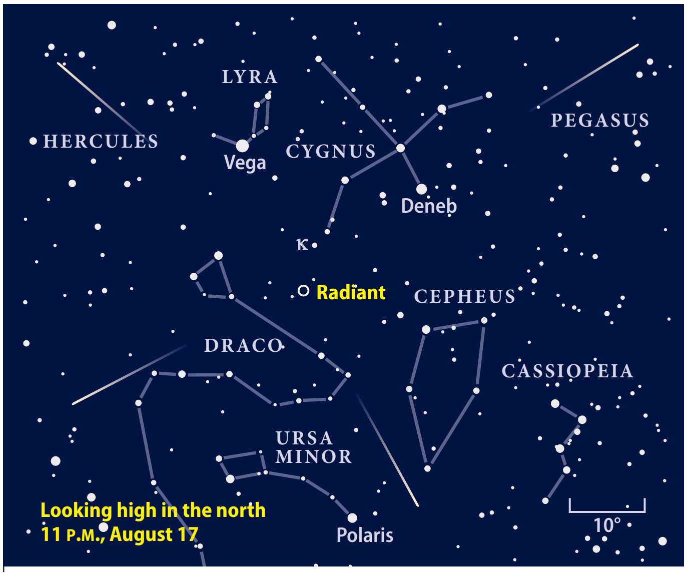
METEORS AND MOONS

Shooting stars pepper the night sky as the Perseid meteor shower reaches its peak. Friction with our atmosphere incinerates this veil of cosmic dust 50 to 75 miles above our heads.

Hero worship

Everyone's favorite meteor shower, the Perseids, peaks the night of August 12/13. Unfortunately, a bright gibbous Moon adversely affects viewing this year. The hours after midnight are usually the best for viewing the Perseids, but the Moon lies just 60° from the shower's radiant in Perseus the Hero. The Moon rises with the radiant and brightens the sky for the rest of the night. Still, many brighter Perseids will shine through, and observers with clear skies can expect to see 30 or so meteors per hour. The Perseids typically produce lots of bright meteors, particularly near dawn — when the impact velocity of the meteoroids with Earth is highest.

Another meteor shower this month may be worth a look. The Kappa Cygnids peak the night of August 17/18. Although this shower has nowhere near the activity level of the Perseids, the Kappa Cygnid radiant remains high all night, and the shower's occasionally bright, slow-moving meteors will catch your eye. Other minor showers are active during August, notably several branches of showers emanating from Aquarius. They add to the popular perception that August is "meteor month."



ASTRONOMY: ROEN KELLY

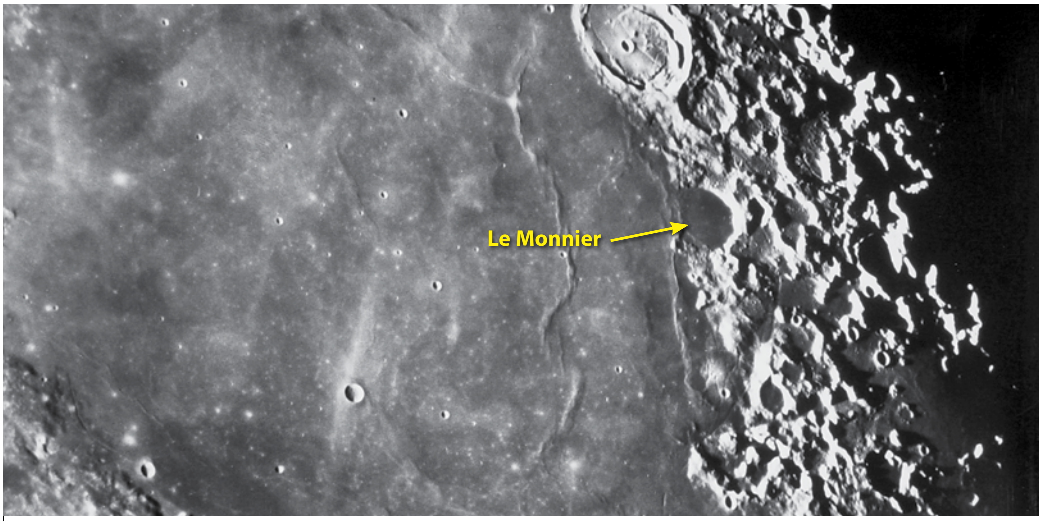
THE KAPPA CYGNID METEOR SHOWER tends to produce slow, bright meteors. This year, a waning crescent Moon won't interfere.

On the trail of Luna

The flooded crater Le Monnier lies along the eastern shore of Mare Serenitatis, nestled against the Taurus Mountains. Named after the 18th-century French astronomer and physicist Pierre Charles Le Monnier, the crater looks like a small bay. You can find 38-mile-wide Le Monnier just south of the complex crater Posidonius. After Full Moon, as the Sun sets over Mare Serenitatis, several wrinkle ridges come into plain view. One called Dorsa Smirnov runs across the mare's entire eastern flank. Another ridge runs south from Posidonius across the western side of Le Monnier.

A low Sun angle reveals a less obvious ridge where you'd expect to see Le Monnier's lost wall. For decades, geologists have suggested the Serenitatis basin slumped because of the weight of overlying lava, creating this eastern ridge. As the Sun sets over the crater, these subtle wrinkles in the lava light up and look like bright "walls" across the mare plains.

In January 1973, the Soviet spacecraft Luna 21 touched down near the crater's southern rim. It subsequently released the Lunokhod 2 rover that trekked 23 miles across Le Monnier. To Le Monnier's south, you'll find the tiny crater Littrow, located near the Apollo 17 landing site.



LUNAR CRATER LE MONNIER lies on the eastern edge on Mare Serenitatis, near several wrinkle ridges apparent under grazing sunlight. FROM *CONSOLIDATED LUNAR ATLAS* (LPL/UA)

COMETS AND ASTEROIDS

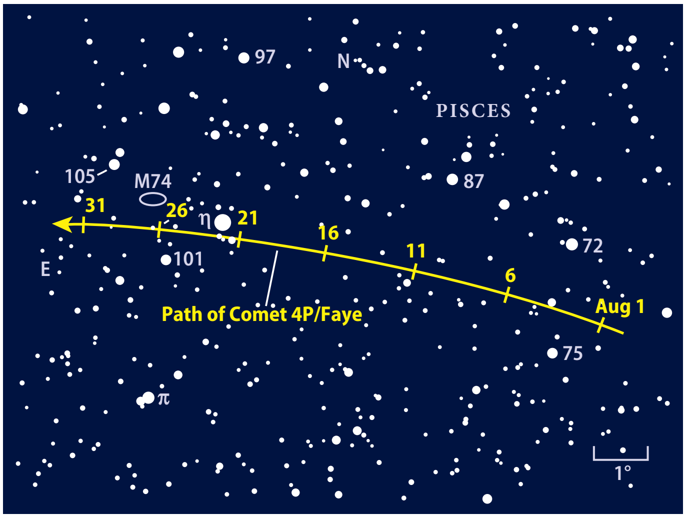
Moderately bright asteroids are easy to follow from the city because their light is concentrated in a point. Seeing their fainter comet cousins, on the other hand, requires a dark sky.

Midnight maneuver

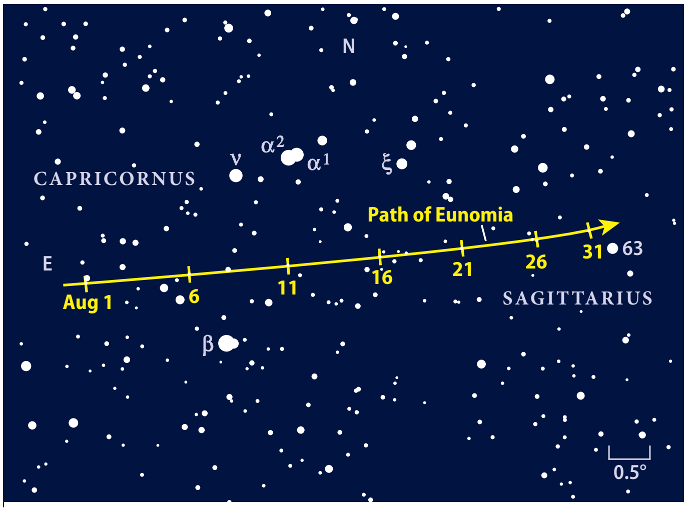
Avid deep-sky observers typically put a couple of comets on their observing lists. After all, a thread of history ties us to Charles Messier, the first comet-hunter who carefully logged deep-sky objects. And a dirty snowball in our solar system shares some visual characteristics with distant galaxies. Experience in recognizing faint comets helps if you accidentally come across a new one — which can happen.

On any given night, a few 12th-magnitude comets float against the starry backdrop, just a little too faint for most observers. This month also provides a brighter comet, however. Comet 4P/Faye should glow around 10th magnitude once it climbs away from the murky horizon after midnight. And astronomers predict it will brighten to 8th magnitude in the next couple of months. The "4P" designation means Faye was the 4th comet recognized as periodic. It takes 7.5 years to revolve around the Sun, and we get a decent look only every 15 years when the Sun isn't in the way. Because Comet Faye never comes closer to the Sun than the orbit of Mars, it is destined to remain modest in appearance.

Once the Moon leaves the midnight sky during August's final 10 days, Faye will be worth pursuing. On the 22nd, it slips a mere 15' (half the Moon's apparent size) south of the star Eta (η) Piscium. For a couple of nights centered on the 26th, it shares a low-power field with the princely face-on spiral galaxy M74. M74 surprises many observers because its bright core is small compared with the overall size listed in reference books. The outer halo is large but faint. You won't see it unless you observe under a dark sky.



COMET 4P/FAYE should glow at 10th magnitude in late August as it passes through Pisces near the galaxy M74. *ASTRONOMY*: ROEN KELLY



ASTRONOMY: ROEN KELLY

ASTEROID EUNOMIA passes near the lovely double star Alpha (α) Capricorni as the space rock brightens to magnitude 8.4.

A month for rocks

When Earth moves between the Sun and a solar system object, the object lies opposite the Sun in our sky and is at "opposition." Ignoring a few subtleties, this is when an asteroid lies closest to us and appears brightest. Asteroids 1 Ceres, 6 Hebe, and 15 Eunomia are all now at their best. Ceres glows brightest, at magnitude 7.6, but it's hiding out in the rich star fields of Piscis Austrinus. And we covered Hebe on page 57. Here, we'll focus on Eunomia because it sails through Capricornus, not far from the beautiful binocular double star Alpha (α) Cap. Sharp eyes can split this stellar pair without optical aid.

Have a look the night of August 8, when Eunomia makes a tight pair with a background star of similar brightness. Can you see the asteroid's motion in as little as an hour?

Only the shadow knows

Although most observers are happy to watch the sky, some like to advance our knowledge of the cosmos. If you're among this latter group, you can help determine the shape of an asteroid this month. In the hour or so before dawn August 21, asteroid 144 Vibilia passes in front of a 10th-magnitude star, making the star disappear for a few seconds. If you live close to a line running from Oklahoma through Lake Ontario to Montreal, think about observing this event. All you need to know can be found at the web site asteroidoccultation.com. ■

Classic rock

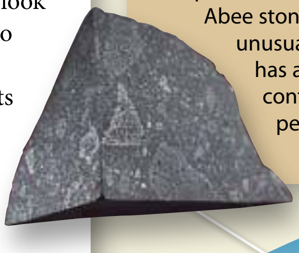
With almost no metals, stone meteorites are the most common in space but tough to find on Earth. /// BY MICHAEL E. BAKICH

Recovery of most stone meteorites happens because people see them fall. Stones are tough to identify — they look like Earth rocks. Meteorite hunters are hard pressed to pick out a stone meteorite on most terrain.

Exceptions exist, however. The ice-covered deserts of Antarctica and the vast sand dunes of northwest Africa make perfect hunting grounds because of the lack of rock. ◼

MAP: NASA'S EARTH OBSERVATORY/FRANCIS REDDY/*ASTRONOMY*: ROEN KELLY

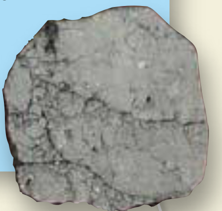
METEORITE IMAGES: ROBERT HAAG, EXCEPT WHERE NOTED



Abee (Alberta)

Enstatite chondrite — 155 grams

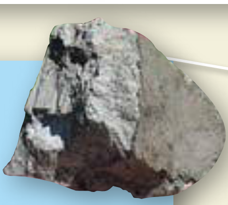
Witnesses saw this meteorite fall June 9, 1953. They found a stone weighing nearly 107 kilograms in a crater 2 meters deep and 1 meter wide. The Abee stone meteorite is unusual because it has a high total iron content — 32.5 percent.



NWA 482 (Morocco)

Lunar achondrite — 27.7g

A buyer purchased a 1,015-gram stone in Alnif, Morocco, in 2001. NWA 482 is the only oriented lunar meteorite found, meaning its passage through the atmosphere melted the meteorite's exterior, forming a pattern of flow lines.



Norton County (Kansas)

Aubrite achondrite — 889g

This witnessed fall occurred February 18, 1948. More than 100 rocks were recovered, with the largest single specimen weighing more than a ton. This meteorite has a lightly colored fusion crust because of its low iron content.

Pasamonte (New Mexico)

Eucrite achondrite — 41g

About 75 golf-ball-size stones fell March 24, 1933, from a fireball that outshone the Sun. This meteorite's interior has a soft ash-like texture.

Pena Blanca Springs (Texas)

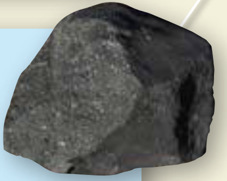
Aubrite achondrite — 11.5 kg

Ranch workers driving a truck heard this meteorite break up in the air. The ranch's cook saw it plunge into a murky pond 14.6 kilometers southeast of Marathon, Texas, August 2, 1946. The men partially drained the pond and recovered a total of 70.4 kilograms of this meteorite.

Colony (Oklahoma)

Carbonaceous chondrite — 164g

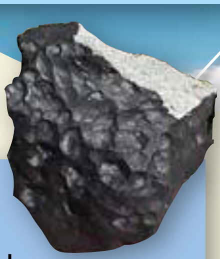
A farmer recovered a single 3.9-kg, highly weathered stone in 1975 from the tines of his cotton cultivator. In 1980, the great meteorite hunter Harvey H. Nininger identified the specimen as meteoritic.



Allende (Mexico)

Carbonaceous chondrite — 17 kg

Thousands of stones fell on and near Allende, Mexico, February 8, 1969, at 1:50 A.M. Analysis shows a 23.8-percent iron content. Calcium and aluminum inclusions date this meteorite 100 million years older than Earth.



La Criolla (Argentina)

L6 chondrite — 6.1 kg

After a bright fireball and many detonations, several dozen pieces of this stone fell over an 8-kilometer-long region east of La Criolla, Argentina. The pictured stone landed in the mayor's yard.

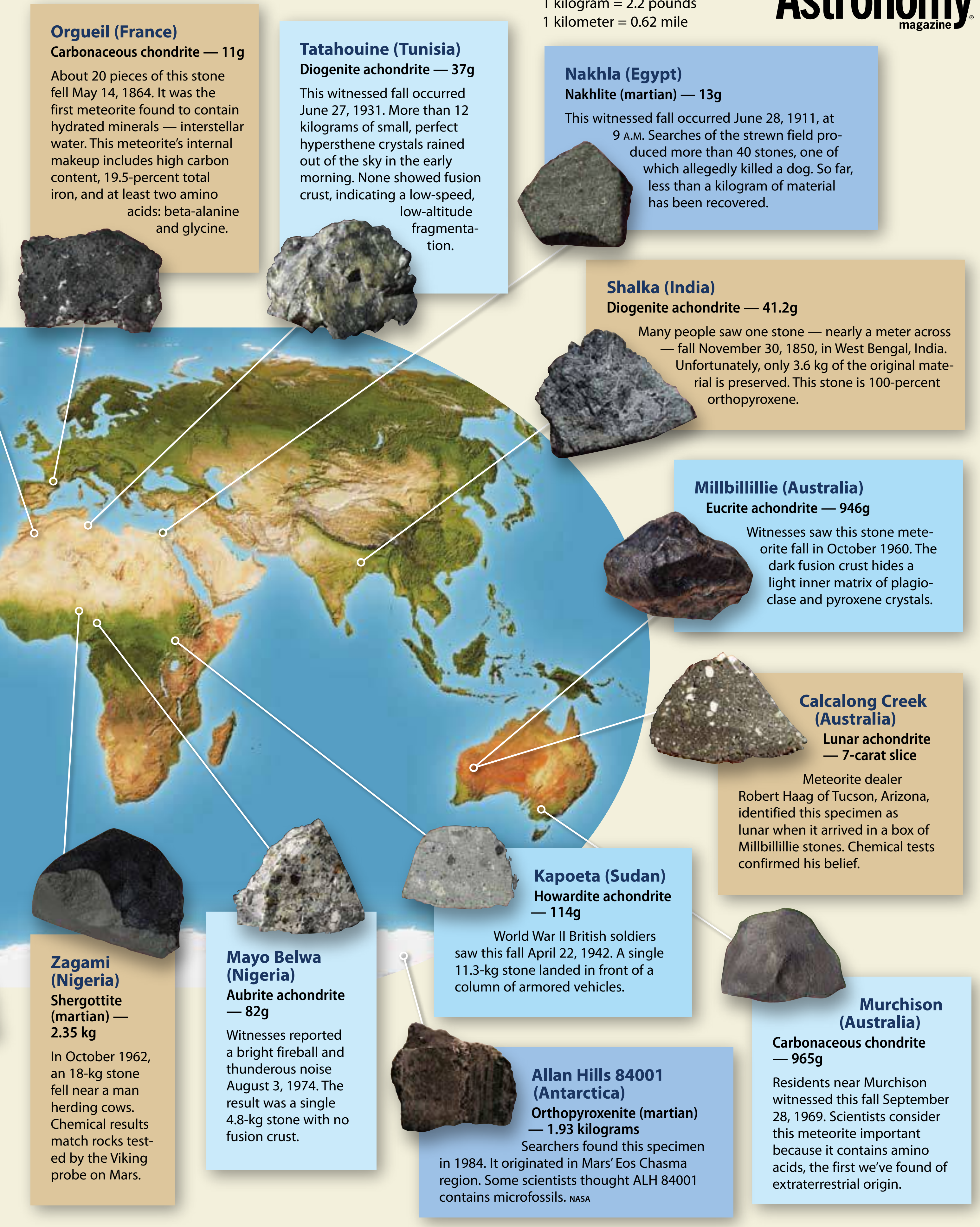
D'Orbigny (Argentina)

Angrite achondrite — 88g

The witnessed fall of this stone occurred in 1979 near Buenos Aires. One 16-kg stone was recovered but was not recognized as a meteorite until some 20 years later.

Astronomy
magazine

1 gram = 0.035 ounce
1 kilogram = 2.2 pounds
1 kilometer = 0.62 mile



Orgueil (France)

Carbonaceous chondrite — 11g

About 20 pieces of this stone fell May 14, 1864. It was the first meteorite found to contain hydrated minerals — interstellar water. This meteorite's internal makeup includes high carbon content, 19.5-percent total iron, and at least two amino acids: beta-alanine and glycine.

Tatahouine (Tunisia)

Diogenite achondrite — 37g

This witnessed fall occurred June 27, 1931. More than 12 kilograms of small, perfect hypersthene crystals rained out of the sky in the early morning. None showed fusion crust, indicating a low-speed, low-altitude fragmentation.

Nakhla (Egypt)

Nakhlite (martian) — 13g

This witnessed fall occurred June 28, 1911, at 9 A.M. Searches of the strewn field produced more than 40 stones, one of which allegedly killed a dog. So far, less than a kilogram of material has been recovered.

Shalka (India)

Diogenite achondrite — 41.2g

Many people saw one stone — nearly a meter across — fall November 30, 1850, in West Bengal, India. Unfortunately, only 3.6 kg of the original material is preserved. This stone is 100-percent orthopyroxene.

Millbillillie (Australia)

Eucrite achondrite — 946g

Witnesses saw this stone meteorite fall in October 1960. The dark fusion crust hides a light inner matrix of plagioclase and pyroxene crystals.

Calcalong Creek (Australia)

Lunar achondrite — 7-carat slice

Meteorite dealer Robert Haag of Tucson, Arizona, identified this specimen as lunar when it arrived in a box of Millbillillie stones. Chemical tests confirmed his belief.

Zagami (Nigeria)

Shergottite (martian) — 2.35 kg

In October 1962, an 18-kg stone fell near a man herding cows. Chemical results match rocks tested by the Viking probe on Mars.

Mayo Belwa (Nigeria)

Aubrite achondrite — 82g

Witnesses reported a bright fireball and thunderous noise August 3, 1974. The result was a single 4.8-kg stone with no fusion crust.

Kapoeta (Sudan)

Howardite achondrite — 114g

World War II British soldiers saw this fall April 22, 1942. A single 11.3-kg stone landed in front of a column of armored vehicles.

Allan Hills 84001 (Antarctica)

Orthopyroxenite (martian) — 1.93 kilograms

Searchers found this specimen in 1984. It originated in Mars' Eos Chasma region. Some scientists thought ALH 84001 contains microfossils. NASA

Murchison (Australia)

Carbonaceous chondrite — 965g

Residents near Murchison witnessed this fall September 28, 1969. Scientists consider this meteorite important because it contains amino acids, the first we've found of extraterrestrial origin.

{ PLANETARY SCIENCE }

The great interplanetary rock swap

Some meteorites come from the Moon, others from Mars. Here's how they arrive. /// BY BILL COOKE

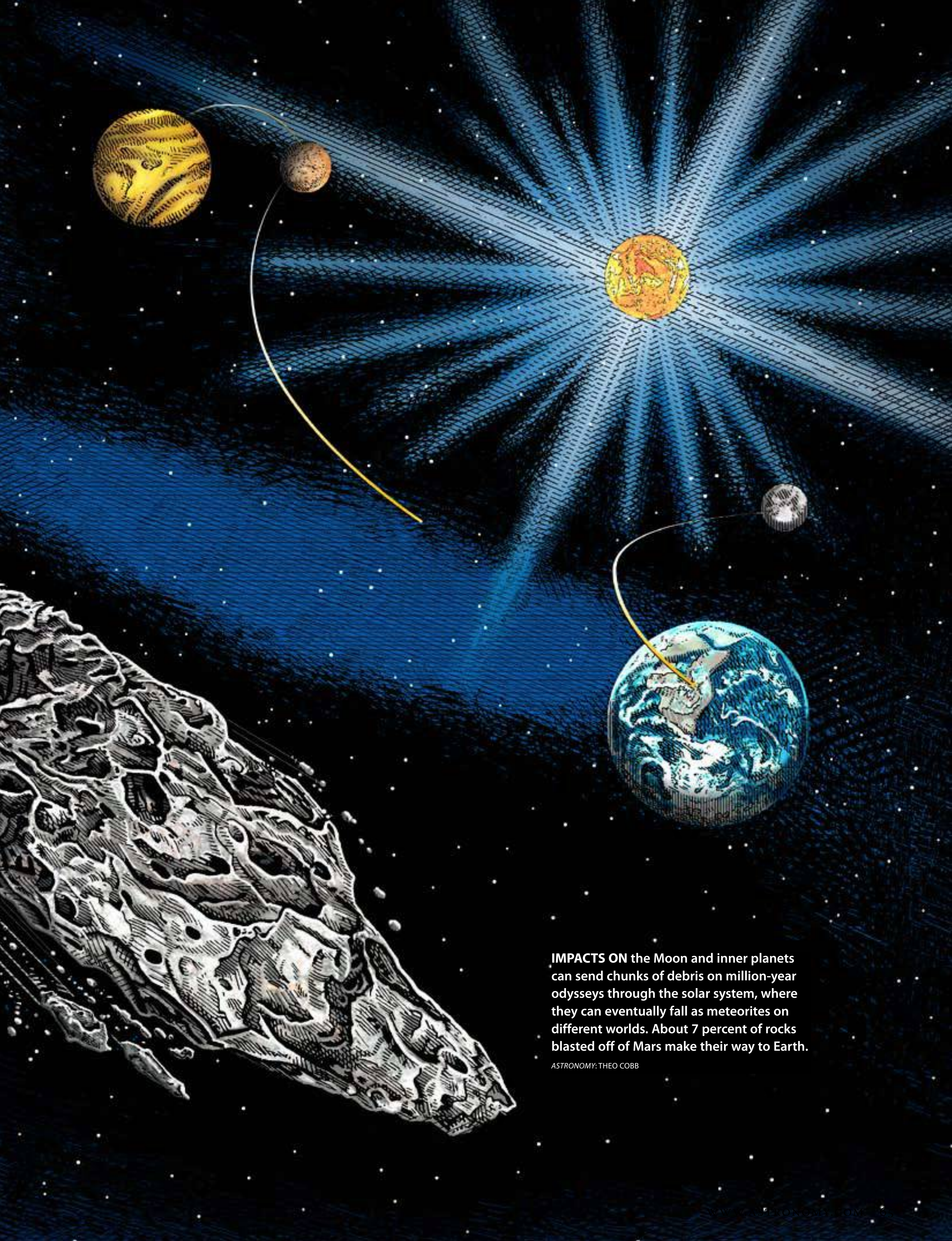
We take it for granted today, but our understanding that meteorites fall from the sky is only about 200 years old. And throughout much of those two centuries, scientists were able to do little more than speculate on meteorite origins. Some thought they were from the Moon, while others thought Mars, Venus, or asteroids were likely sources. A few suggested meteorites were homeless wanderers, migrating among star systems.

By the 1950s, advances in photography allowed planetary scientists to calculate the orbits of some bright meteors. All of these orbits extended out to distances between Mars and Jupiter, in the main asteroid belt. As time and technology progressed, scientists found good matches between asteroid spectra and meteorite compositions. Most meteorites are asteroid chips, products of collisions between objects in the main belt.

Most, but not all. The few meteorites that didn't fit into this picture were puzzling. This includes the falls at Chassigny, France, in 1815; at Shergotty, India, in 1865; and at El Nakhla, Egypt, in 1911 (where one falling fragment reportedly killed a dog).

Measurements indicated those meteorites first solidified from molten rock on a larger body relatively recently — between 150 million and 1.5 billion years ago.

Bill Cooke *is an astronomer at NASA's Marshall Space Flight Center in Huntsville, Alabama. His previous article for* Astronomy *was May's "Fatal attraction."*



IMPACTS ON the Moon and inner planets can send chunks of debris on million-year odysseys through the solar system, where they can eventually fall as meteorites on different worlds. About 7 percent of rocks blasted off of Mars make their way to Earth.

ASTRONOMY: THEO COBB

ALH84001 is the best known SNC meteorite. Found in Antarctica's Allan Hills ice field in 1984, the 5-inch-wide (12 centimeters) basalt sparked considerable debate in the 1990s, when some scientists suggested some unusual microscopic structures inside the rock are martian fossils. Most scientists weren't convinced. NASA

DEBRIS BLASTED off of the Moon can collide with Earth in as little as 50,000 years. MAC88105 is a lunar meteorite found in Antarctica's MacAlpine Hills ice field in 1988. The Moon's low escape speed and nearness to us means that up to 40 percent of any debris escaping it will eventually fall on Earth. NASA

MARS EXPLORATION Rover Opportunity found the first meteorite of any type ever identified on another planet. The pitted, basketball-size object, dubbed Heat Shield Rock, is mostly made of iron and nickel. The rock is most likely debris from the asteroid belt, but pieces of Earth must lie somewhere on Mars, too.

NASA/JPL/CORNELL

Asteroidal meteorites are far older. The young crystallization ages of the rocks in question meant they came from a body that was geologically active in the recent past. Asteroids do not have volcanoes, and the Moon has been geologically dead for eons. This leaves Venus and Mars — the only nearby planets where volcanoes have been active within the past 2 billion years.

Stone cold

Planetary scientists classify these oddball rocks as SNC meteorites (after Shergotty, Nakhla, and Chassigny). Membership of the SNC group grew as Antarctic exploration became well established. Uninviting as it is, Antarctica turns out to be the perfect place for hunting meteorites.

Meteorites striking Antarctic ice fields become embedded in the ice, which slowly flows over time. In certain areas, underlying rock forces the ice upward, where it's at the mercy of the region's dry winds. Wind erodes ice around the embedded meteorite and leaves it exposed on the surface, easily visible to scientists. An additional bonus: Antarctic meteorites are generally better preserved than their cousins found in temperate climates. Scientists now recognize at least 34 members in the SNC meteorite clan.

In 1985, researchers settled the question of SNC origins. They determined the composition of gas bubbles trapped deep in the meteorites' interiors. The gas was similar in composition to that of the martian atmosphere measured by the Viking 1 and 2 landers. There was no doubt: SNC meteorites come from Mars.

Swapping rocks

Knowing how long a meteorite has been in space helps narrow down its possible source. The amounts of certain isotopes of helium, argon, and neon gradually increase inside a meteorite in space because energetic cosmic rays bombard the rock. Cosmic rays can't penetrate more than about 7 feet (2.1 meters) of rock, so the isotopes build up only after the meteorite has been knocked off of its parent body.

Measurements of SNC cosmic-ray-exposure (CRE) ages sparked an intense debate within the scientific community in the 1970s and 1980s. Based on computer simulations, planetary scientists thought a rock knocked off of Mars might take 100 million years or more to find its way to Earth. Yet, measurements indicated some SNC meteorites had spent less than 15 million years in space. Chemical analyses said the rocks were from Mars, but celestial mechanics said they couldn't get here fast enough. Something was missing.

WITHIN 2.5 MILLION years, 2 percent of any debris escaping Mars can make its way to Earth.

Those first dynamical simulations left out an important effect — one caused by gravitational resonances. In some regions of the solar system, a planet's gravitational effects can produce radical changes in a small body's orbit. Consider a meteoroid in an orbit that takes it exactly twice around the Sun for every Earth orbit. The meteoroid always gets a strong tug from Earth at exactly the same place in the rock's orbit. Like pumping a child's swing at the right rhythm, this effect amplifies Earth's orbit-altering abilities.

Incorporating such resonances into simulations has enabled scientists to outline a plausible scenario for getting martian meteorites to Earth fast. First, an asteroid or comet strikes Mars at a shallow angle. As the impactor digs in, it hurls fast-moving debris high above the Red Planet's surface. Some of this debris flies faster than Mars' escape velocity (11,230 mph, or 18,000 km/h). It will not fall back onto the planet, but continue into interplanetary space.

About 10 percent of these escapees eventually will be recaptured and strike Mars, but the rest will wander the solar system. Some will encounter gravitational resonances near Mars. Some of their orbits will be changed so they cross the orbits of Earth (about 7 percent), Venus (7 percent), and Jupiter (10 percent). The remainder will take on eccentric, Sun-grazing orbits. The orbital alterations happen quickly on astronomical timescales: Within 2.5 million years, 2 percent of any debris escaping Mars can make its way to Earth.

Some rocks can take a fast track that brings them to Earth within a few years. Although few in number, these meteorites are important in that they have the best chance of transporting any possible martian microbes to our planet. This lends a new perspective to fears of contaminating Earth with possible martian life in samples returned from future spacecraft. Martian meteorites containing any such life — if it exists — have been landing on Earth for billions of years.

Take the amount of material reaching the destination planet, and divide this by the amount of material that may have escaped from the planet of origin, and you have what planetary scientists call the transfer efficiency. It's an important number, as it gives us some idea about how many meteorites from other planets we can find on Earth — and how many Earth rocks have landed on other planets. Transfer efficiency is about 7 percent for Mars, which, combined with other factors, equates to about 1 martian meteorite larger than 3.5 ounces (100 grams) each month. If Mars, the closest planet, can deliver this much material to Earth, what can we expect from our closest neighbor, the Moon?

Harvest Moon

The Moon delivers meteorites to Earth in much the same way Mars does, but gravitational resonances aren't needed for a speedy trip. The Moon's low escape speed (5,370 mph, or 8,640 km/h) and proximity result in a transfer efficiency of 40 percent.

Planetary scientists now recognize 39 lunar meteorites (lunaites). Because the Apollo astronauts and Soviet Luna missions returned lunar samples, identification of lunar meteorites is a slam dunk. They all have ratios of manganese to iron similar to Moon rocks and sport CRE ages of 50,000 years or less. Lunaites are important because they come from parts of the lunar surface not sampled by Apollo or Luna. Indeed, there is compelling evidence at least some lunaites come from highlands on the lunar farside, where no spacecraft has landed yet.

But what of meteorites from planets more distant than Mars? Brett Gladman at Canada's University of British Columbia, Jay Melosh at the University of Arizona, and other researchers have calculated the transfer efficiency for Mercury, and they find it to be quite low — perhaps 0.1 percent, about 1⁄70 that of Mars. The main reason is that Mercury recaptures about 75 percent of the meteorites ejected from its surface. About 10 percent of what does escape permanently collides with Venus. Of the 26,000 meteorites scientists know of today, not a single one is considered to be from Mercury.

The odds of finding a meteorite from Venus are also low. Venus has a strong gravitational field and a high escape velocity (23,270 mph, or 37,450 km/h). Accelerating rocks to this speed takes a lot of energy. The more energy required, the less likely it is there'll be an impact large enough to boost a fragment to the necessary speed, so fewer will escape the planet.

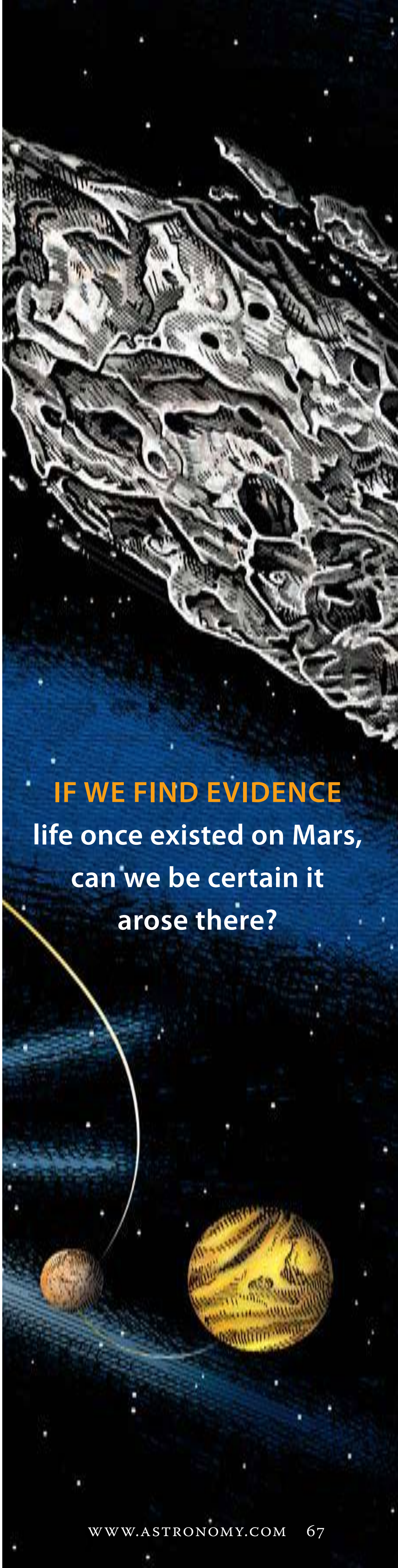
Worse, Venus has a dense atmosphere. Any escaping ejecta must weigh as much as the atmospheric mass above them. For Venus, this means a big chunk of material, which only exacerbates the problem of reaching escape speed. However, for any Venus rocks that make it out of the planet's dense atmosphere, about 30 percent will strike Earth within 12 million years. Venus' transfer efficiency is almost as high as the Moon's. The only barrier to a rain of Venus meteorites is the lack of ejecta reaching the planet's escape speed.

The same constraints — high escape speed and a dense atmosphere — apply to ejecta leaving Earth. Melosh calculates that 30 percent of the rocks knocked off of Earth will reach Venus within 15 million years, and, after a trip lasting 10 times longer, about 5 percent of them may strike Mars.

The notion of Mars, Earth, and Venus exchanging debris — especially in the distant past, when these planets experienced large impacts more frequently — is intriguing. If life once existed on Mars, could it have made its way to Earth, and contributed to the development of life here? And if we find evidence life once existed on Mars, can we be certain it arose there? Did ancient terrestrial microbes hitch a ride to the Red Planet?

There is no denying that the inner planets have exchanged material in the past, and, in small amounts, still do. Earth rocks on Mars and Venus, Venus rocks on Earth and Mars, Mercury rocks on Venus: Some of these may be the prizes of future planetary exploration.

ONLINE EXTRA See Park Forest, Illinois, fireball videos at www.astronomy.com/toc.



IF WE FIND EVIDENCE life once existed on Mars, can we be certain it arose there?

Heavy metal

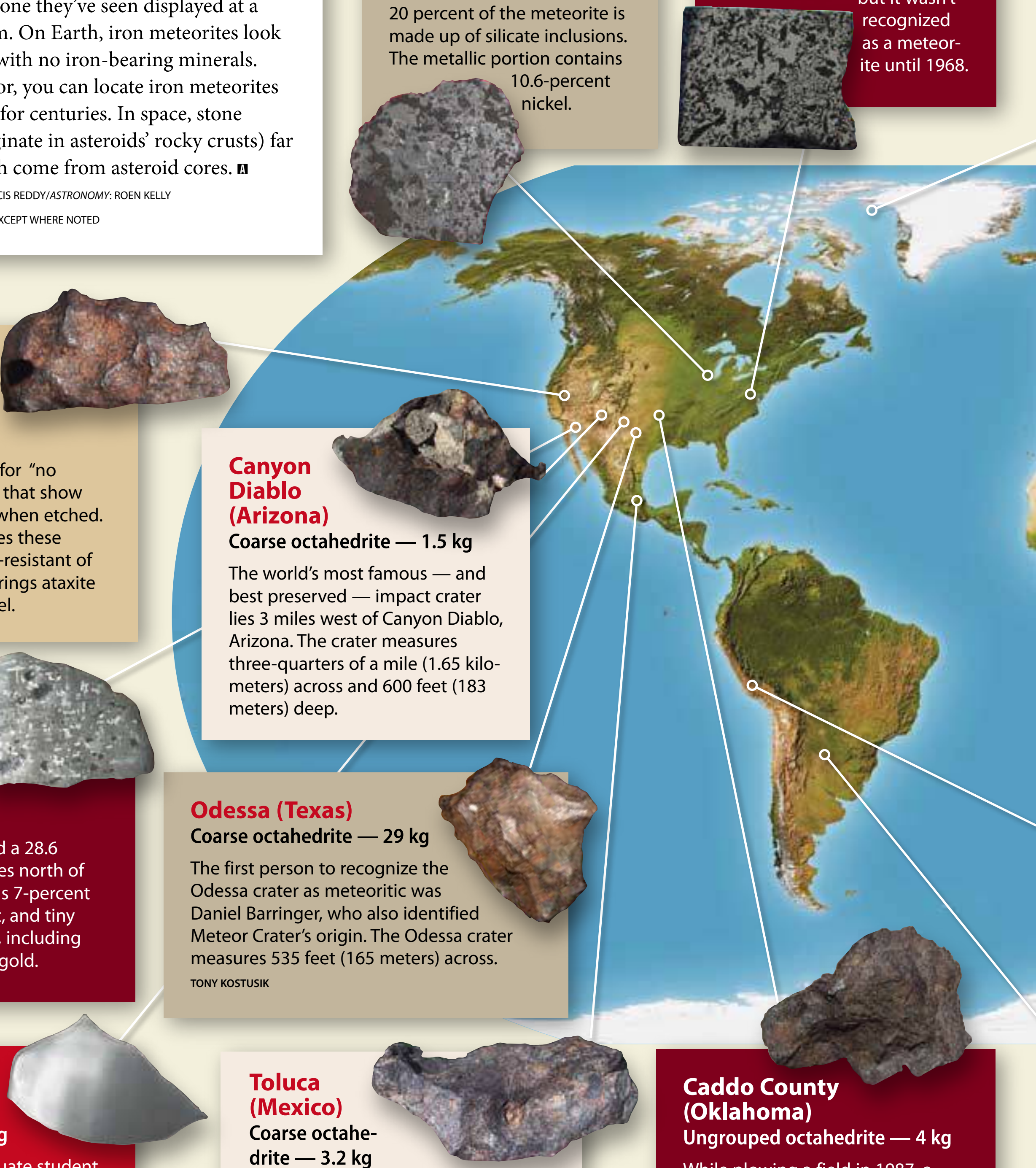
Iron meteorites make up less than 10 percent of space rocks but are easy to identify on Earth. /// BY MICHAEL E. BAKICH

When most people think of a meteorite, they visualize a chunk of iron, perhaps one they've seen displayed at a museum or planetarium. On Earth, iron meteorites look out of place in regions with no iron-bearing minerals.

With a metal detector, you can locate iron meteorites that have lain dormant for centuries. In space, stone meteoroids (which originate in asteroids' rocky crusts) far outnumber irons, which come from asteroid cores. **A**

MAP: NASA'S EARTH OBSERVATORY/FRANCIS REDDY/*ASTRONOMY*: ROEN KELLY

ALL METEORITE IMAGES: ROBERT HAAG, EXCEPT WHERE NOTED



Woodbine (Illinois)

Fine octahedrite — 471grams

In the spring of 1953, farmer Henry Albrecht plowed up a 106-pound (48.2 kg) iron meteorite about a mile west of Woodbine, Illinois. About 20 percent of the meteorite is made up of silicate inclusions. The metallic portion contains 10.6-percent nickel.

Landes (West Virginia)

Ungrouped octahedrite — 337g

Meteoriticists classify this meteorite as chemically anomalous. It contains pyroxenes and 6.3-percent nickel. A single 154-pound (70 kg) specimen was found in 1930, but it wasn't recognized as a meteorite until 1968.

Shingle Springs (California)

Ungrouped ataxite — 456g

Ataxites (from the Greek for "no structure) are meteorites that show no Widmanstätten lines when etched. High nickel content makes these meteorites the most rust-resistant of the irons. The Shingle Springs ataxite contains 17-percent nickel.

Canyon Diablo (Arizona)

Coarse octahedrite — 1.5 kg

The world's most famous — and best preserved — impact crater lies 3 miles west of Canyon Diablo, Arizona. The crater measures three-quarters of a mile (1.65 kilometers) across and 600 feet (183 meters) deep.

Ocotillo (California)

Coarse octahedrite — 738g

A meteorite hunter found a 28.6 kilogram specimen 5 miles north of Ocotillo. The iron contains 7-percent nickel, 0.5-percent cobalt, and tiny amounts of other metals, including 1.65 parts-per-million of gold.

Odessa (Texas)

Coarse octahedrite — 29 kg

The first person to recognize the Odessa crater as meteoritic was Daniel Barringer, who also identified Meteor Crater's origin. The Odessa crater measures 535 feet (165 meters) across.

TONY KOSTUSIK

Tinnie (New Mexico)

Plessitic ataxite — 291g

In 1978, an Afghani graduate student doing research on Barbary sheep found a single 34-pound (15.3 kg) specimen of this meteorite. He gave it to the family he was staying with, who kept it in their living room for 20 years. It contains 18.4-percent nickel.

Toluca (Mexico)

Coarse octahedrite — 3.2 kg

Discovered in 1776 by explorers in Xiquipilco, Mexico, which lies in the Toluca Valley, iron from this meteorite had been used for centuries by natives to make tools. The iron contains 8-percent nickel.

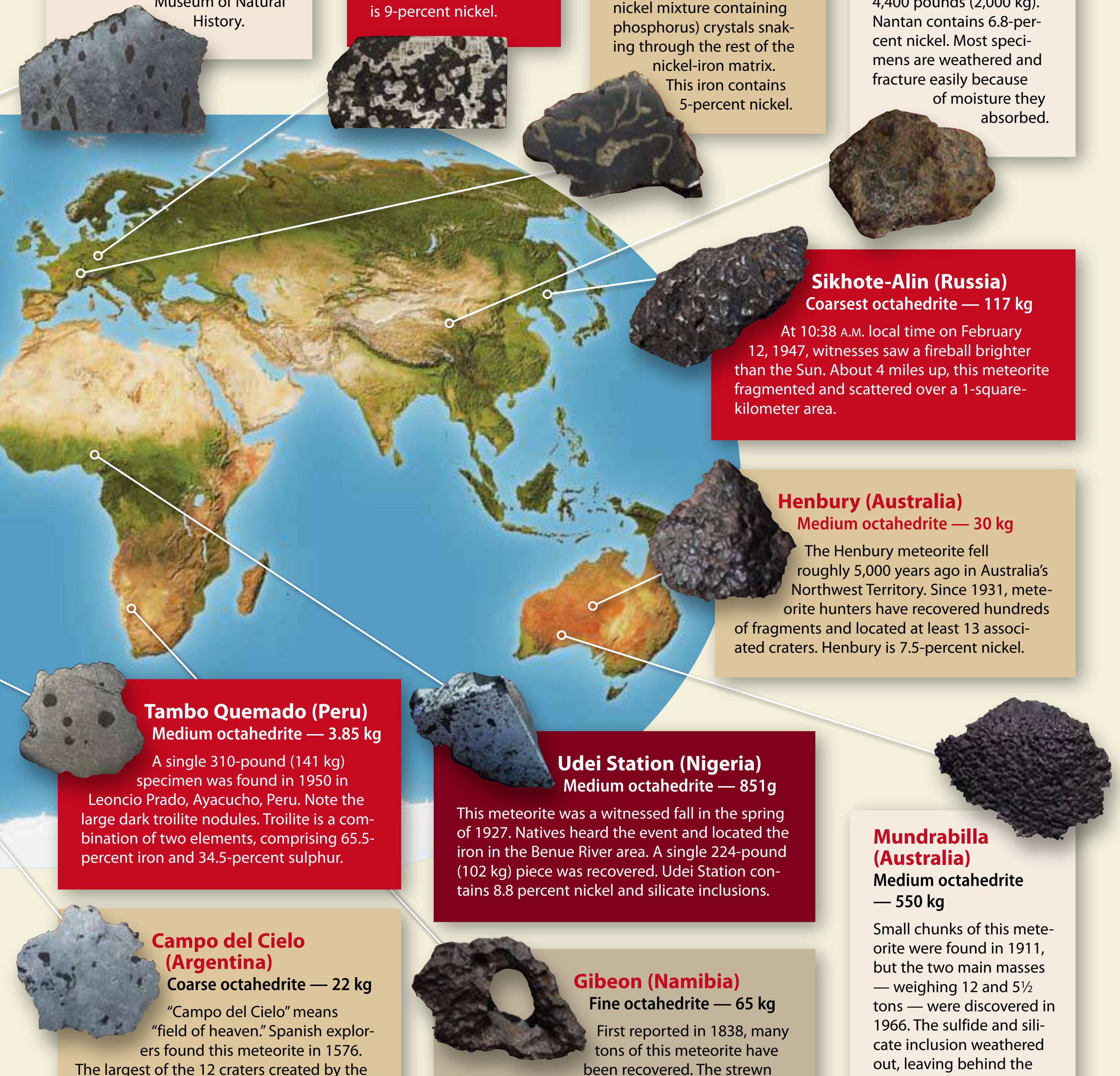
Caddo County (Oklahoma)

Ungrouped octahedrite — 4 kg

While plowing a field in 1987, a farmer found a 35-pound (16.1 kg) specimen and an additional 5 pounds (2.3 kg) of fragments of this meteorite. It contains 9-percent nickel and widely separated, poorly mixed silicate inclusions.

1 gram = 0.035 ounce
1 kilogram = 2.2 pounds
1 kilometer = 0.62 mile

Astronomy magazine



Cape York (Greenland)

Medium octahedrite — 37 kilograms

In 1894, Admiral Robert Peary identified three pieces of Cape York as meteorites. The largest — a 34-ton giant called Ahnighito (the "Tent") — now resides in New York's American Museum of Natural History.

Steinbach (Germany)

Chemically anomalous — 45g

A single specimen of this meteorite, measuring 16 inches (40 cm) across, was found in 1724. Silicate inclusions make up two-thirds of its mass, and the metal is 9-percent nickel.

Twannberg (Switzerland)

Hexahedrite to coarsest octahedrite — 38g

A farmer found a single 35-pound (16 kg) piece in a barley field after he'd finished plowing. Note the large schreibersite (an iron-nickel mixture containing phosphorus) crystals snaking through the rest of the nickel-iron matrix. This iron contains 5-percent nickel.

Nantan (China)

Medium octahedrite — 1.5 kg

Chinese inhabitants witnessed this meteorite fall in 1516. The largest specimen recovered weighs 4,400 pounds (2,000 kg). Nantan contains 6.8-percent nickel. Most specimens are weathered and fracture easily because of moisture they absorbed.

Sikhote-Alin (Russia)

Coarsest octahedrite — 117 kg

At 10:38 A.M. local time on February 12, 1947, witnesses saw a fireball brighter than the Sun. About 4 miles up, this meteorite fragmented and scattered over a 1-square-kilometer area.

Henbury (Australia)

Medium octahedrite — 30 kg

The Henbury meteorite fell roughly 5,000 years ago in Australia's Northwest Territory. Since 1931, meteorite hunters have recovered hundreds of fragments and located at least 13 associated craters. Henbury is 7.5-percent nickel.

Tambo Quemado (Peru)

Medium octahedrite — 3.85 kg

A single 310-pound (141 kg) specimen was found in 1950 in Leoncio Prado, Ayacucho, Peru. Note the large dark troilite nodules. Troilite is a combination of two elements, comprising 65.5-percent iron and 34.5-percent sulphur.

Udei Station (Nigeria)

Medium octahedrite — 851g

This meteorite was a witnessed fall in the spring of 1927. Natives heard the event and located the iron in the Benue River area. A single 224-pound (102 kg) piece was recovered. Udei Station contains 8.8 percent nickel and silicate inclusions.

Mundrabilla (Australia)

Medium octahedrite — 550 kg

Small chunks of this meteorite were found in 1911, but the two main masses — weighing 12 and 5½ tons — were discovered in 1966. The sulfide and silicate inclusion weathered out, leaving behind the distinctive coral-like texture of the nickel-iron.

Campo del Cielo (Argentina)

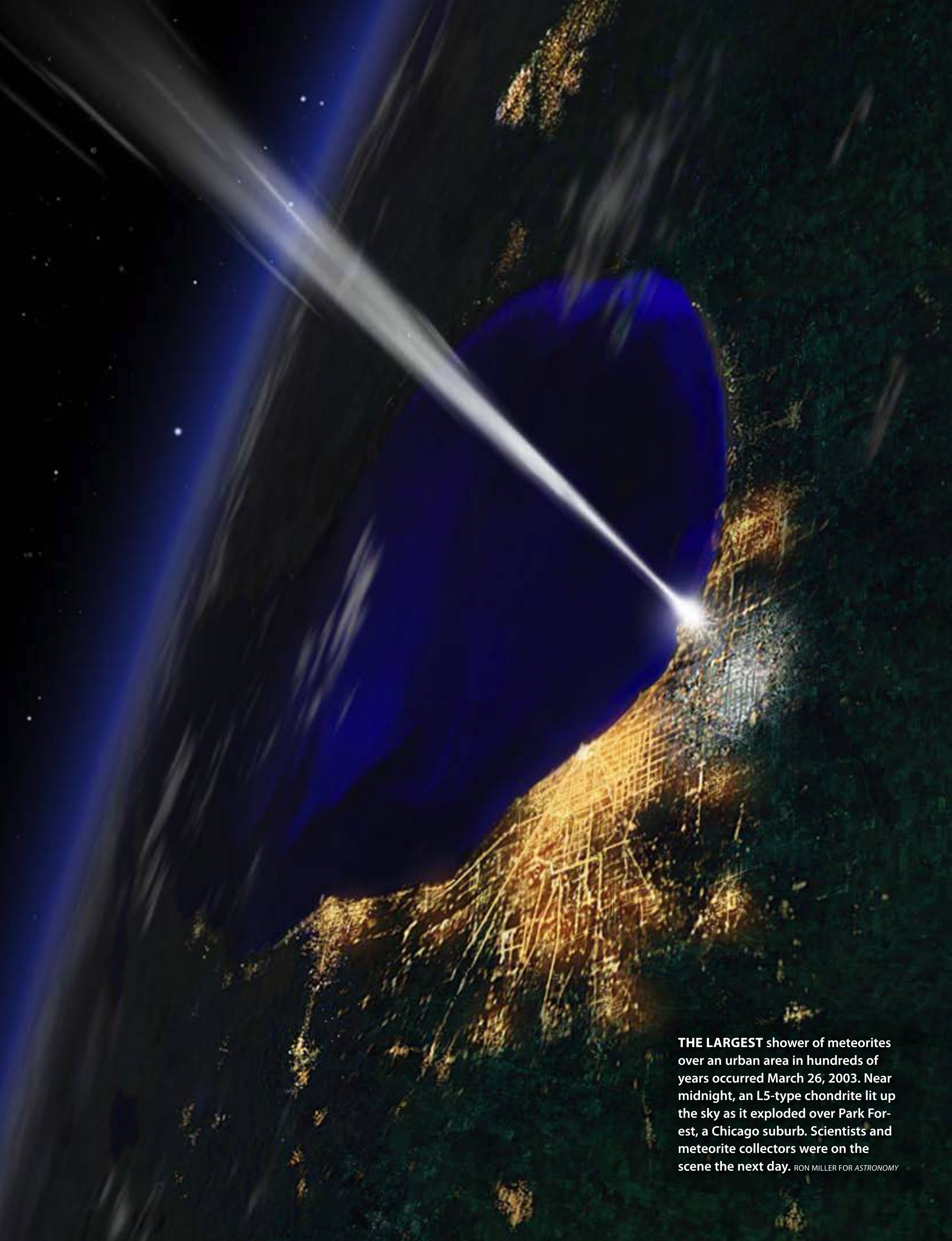
Coarse octahedrite — 22 kg

"Campo del Cielo" means "field of heaven." Spanish explorers found this meteorite in 1576. The largest of the 12 craters created by the fall measures 256 by 213 feet (78 by 65 meters). Campo is 6.6-percent nickel.

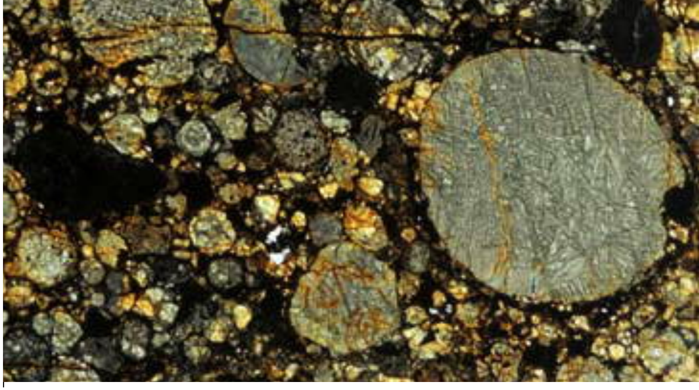
Gibeon (Namibia)

Fine octahedrite — 65 kg

First reported in 1838, many tons of this meteorite have been recovered. The strewn field of the Gibeon fall is the largest in Africa, spanning 182 by 55 miles (400 by 120 km).



THE LARGEST shower of meteorites over an urban area in hundreds of years occurred March 26, 2003. Near midnight, an L5-type chondrite lit up the sky as it exploded over Park Forest, a Chicago suburb. Scientists and meteorite collectors were on the scene the next day. RON MILLER FOR *ASTRONOMY*



SPHERICAL CHONDRULES appear in this cutaway of an L4-type chondritic meteorite. ALL IMAGES BY O. RICHARD NORTON UNLESS OTHERWISE CREDITED

How to start your meteorite collection

Here's everything you need to start acquiring space rocks. /// BY O. RICHARD NORTON

Some 40,000 tons of cast-off asteroid and comet material enters Earth's atmosphere every year. Of this, less than 1 percent survives passage through the air. But those space rocks that hit the ground command the attention of sharp-eyed observers who seek to recover them. With a little knowledge, one of those observers could be you.

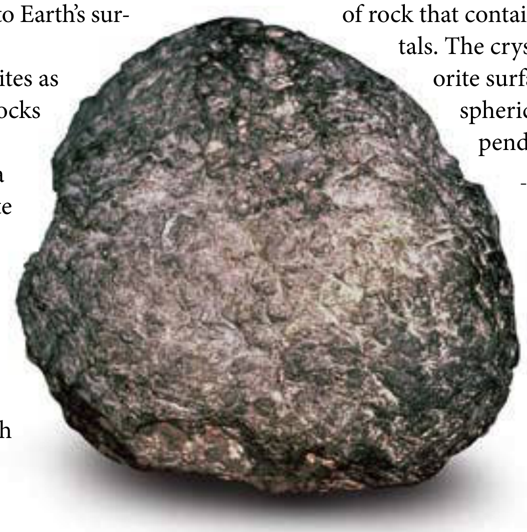
With few exceptions, meteorites are chips off of asteroids. We call the chips "meteoroids" when they're in space and the asteroids that spawned them "asteroid parent bodies." Most asteroids remain locked in stable orbits in the asteroid belt between Mars and Jupiter. But Jupiter's powerful gravitational force perturbs certain main-belt asteroids into less stable orbits, redirecting them across the asteroid belt and raising the possibility of eventual collisions. Many will become Earth-crossing asteroids, and some may collide with our planet. The chips that occasionally make it to Earth's surface are called "meteorites."

Although people have collected meteorites as curiosities for more than 2 centuries, the rocks weren't recognized as extraterrestrial until relatively recently. On November 7, 1492, a 280-pound (127 kilograms) stone meteorite announced its arrival with a sonic boom. Before a lone eyewitness, the rock dropped into a wheat field near the village of Ensisheim, France — it's the Western Hemisphere's oldest witnessed fall. Several years ago, I acquired a piece of this specimen, and I continue to be amazed that such priceless wonders are available to collectors today. Despite many other witnessed falls, scientists remained skeptical about reports of rocks falling from the sky until the late 18th and early 19th centuries, when several dramatic arrivals laid the question to rest and gave way to meteorite science.

Getting started

Meteoritics is a hybrid science — geology and mineralogy share the stage with astronomy — so there's no avoiding some new terminology. But, then, this is true when starting any collection.

Meteorites come in three basic types: stone, iron, and stony-iron. Stone meteorites are the most abundant, and chondrites constitute the most common subclass. In fact, about 82 percent of the world's known witnessed falls are chondrites. A chondrite is a kind of rock that contains spherical assemblages of mineral crystals. The crystals can be seen easily on a polished meteorite surface by using just a 10x magnifier. These spherical objects, called chondrules, existed independently before they became incorporated

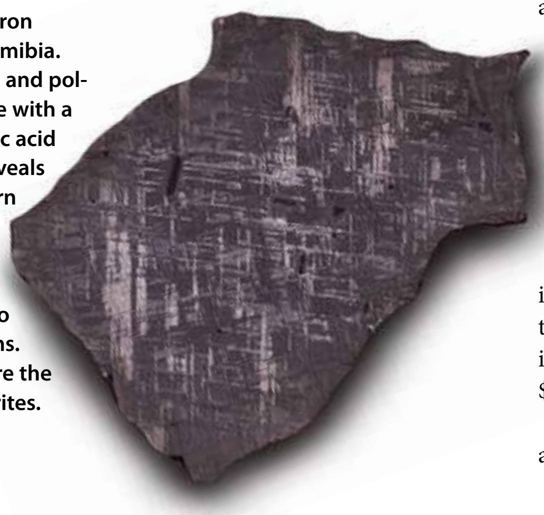


THE ENSISHEIM stone meteorite fell November 7, 1492. After centuries of souvenir-taking and scientific sampling, the LL6-type chondrite is less than half its original 280-pound (127 kilogram) weight. Dark areas (top) are part of the fusion crust produced during the rock's fiery entry. THOMAS C. MARVIN

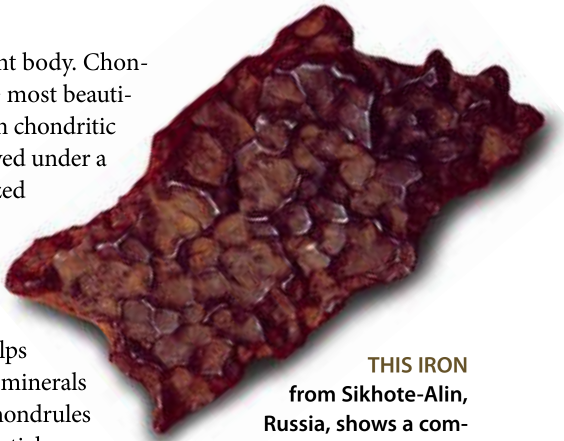
METEORITES AND THEIR SOURCES

Group	Percentage of falls	Postulated source bodies
L	38.0	S(IV) asteroids
H	34.1	6 Hebe [S(IV)]
LL	7.9	S(IV) asteroids
Irons	4.2	M asteroids
Eucrites	2.7	4 Vesta (V)
Howardites	2.1	4 Vesta (V)
CM	1.7	19 Fortuna (G, Ch)
Diogenites	1.2	4 Vesta (V)
Aubrites	1.0	3103 Eger
EH	0.8	M asteroids
EL	0.7	M asteroids
Mesosiderites	0.7	M asteroids
CV	0.6	K asteroids
CI	0.5	C asteroids
CO	0.5	221 Eos (K)
Pallasites	0.5	A asteroids
Ureilites	0.5	S asteroids
“Martian”	0.4	Mars
CR	0.3	C asteroids
CK	0.3	C asteroids
CB	0.3	M asteroids
Acapulcoites	0.1	S asteroids
Angrites	0.1	3628 Božněmcová
Lodranites	0.1	S asteroids
R	0.1	A or S asteroids
Winonaites	0.1	S asteroids
Tagish Lake	0.1	D or T asteroids
Brachinites	Finds only	A asteroids
CH	Finds only	C or M asteroids
“Lunar”	Finds only	Moon

AFTER THOMAS BURBINE ET AL., 2006



THIS GIBEON iron comes from Namibia. Etching the cut and polished meteorite with a mixture of nitric acid and ethanol reveals a unique pattern called a Widmanstätten structure, which is used to classify the irons. Gibeon irons are the finest octahedrites.



THIS IRON from Sikhote-Alin, Russia, shows a complex exterior with many “thumbprints.” This meteorite and thousands of others fell February 12, 1947, in the Sikhote-Alin Mountains.

into an asteroid parent body. Chondrules are among the most beautiful structures found in chondritic meteorites when viewed under a microscope in polarized light. (Polarized light is filtered to let only light waves vibrating in a certain direction pass through. This helps scientists identify the minerals in a sample.) Many chondrules show clear signs of partial or complete melting and recrystallization sometime in their histories.

Among the chondrite class, there are 15 subtypes based on differences in chemical and mineral composition as well as internal texture (grain size and shape, among other things). Not surprisingly, the most common chondrites are called ordinary chondrites. In fact, these are by far the most common meteorites. But don’t let the name fool you — there’s nothing ordinary about them. Because these rocks’ interiors show no evidence of melting and differentiation, scientists consider them primitive. They are as they formed 4.56 billion years ago. They do show signs of being heated, but not to their melting points.

Initially, your collection will be a bit heavy on the chondrite side. Over the last decade, thousands of ordinary chondrites have been found in the hot deserts of the Middle East. There, they’ve lain fully exposed on the surface for thousands of years. Meteorites from Northwest Africa are among the most popular and plentiful; nomads trained and hired by meteorite collectors or dealers have collected a large fraction of them. These meteorites are among the least expensive: They sell on the market for under $1 per gram (0.035 ounce).

Occasionally, unwitting collectors have made spectacular finds. This usually involves so-called asteroidal achondrites. These rocks are among the rarest of the stone meteorites. Achondrites don’t have chondrules, which means they probably originated from chondritic asteroid parent bodies that partially or totally melted. Once a body melts, heavier elements tend to sink to its center, while lighter elements float to the top. This process of differentiation is how planets acquired their internal structures (core, mantle, and crust).

One of the largest asteroids, 4 Vesta, is a source of asteroidal achondrites. Vesta is a differentiated asteroid with lava flows on its surface. The HED family of achondrites (named for the howardite, eucrite, and diogenite subclasses) come from Vesta or its parent body and are among the most prized achondrites. If you aim for a piece of Vesta in your collection, note that eucrites are both the most plentiful and the easiest on the wallet.

Top dollar

Achondrites also include the rarest and most expensive meteorites — those from the Moon and Mars. Don’t plan on adding one of these to your collection unless you’ve just won the lottery. Depending on the type, Mars meteorites sell for anywhere from $500 to $1,000 or more per gram.

During the Apollo Moon program of the 1960s and 1970s, astronauts gathered more than 800 pounds of lunar rock. These

FIRST STEPS

If you want to buy

A good place to start a collection is in rock shops or at gem and mineral shows. The world's largest "meteorite show" is the Tucson Gem and Mineral Show, held every February in Tucson, Arizona. There are also major shows in Tokyo and Munich, Germany, as well as many smaller ones in every U.S. state and many other countries. There are many reputable dealers online, and eBay offers a large selection.

If you want to search

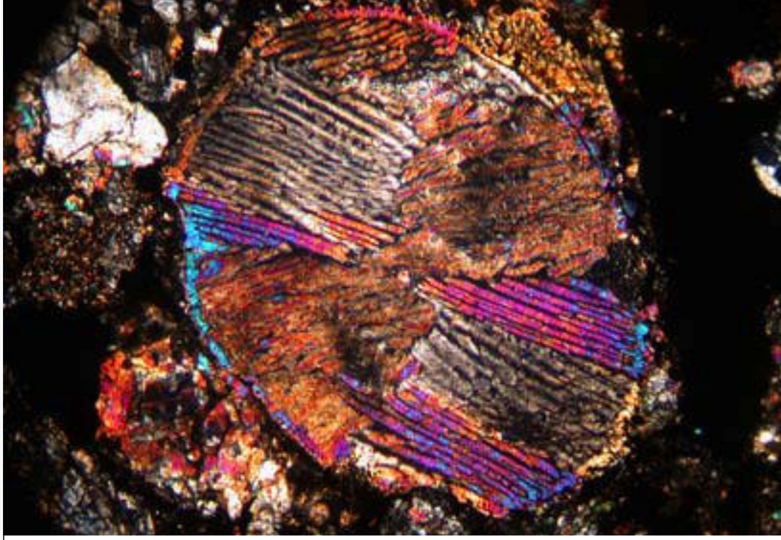
Arid lands, such as the deserts of the southwestern United States and the Near East, are fertile ground for meteorite hunters. The rocks can fall anywhere, but finding them is more difficult where heavy vegetation quickly covers fresh falls or heavy rain weathers the meteorites. The best place to search is where there are no native black rocks, so any black rock you find is a potential meteorite. Know your local rocks, and look for the ones that are different.

HUNTERS FOUND this 2,573-pound (1,167 kg) iron meteorite in 1938 on a lava flow near Goose Lake, California.

samples, which are still used for research, are off-limits to collectors. But scientists have recovered at least 39 lunar meteorites (lunaites) from Antarctica and the Middle East. All meteorites found in Antarctica become the property of the government controlling the sector where the meteorite is recovered; the rocks seldom fall into collectors' hands. Over the last decade, more Mars and lunar meteorites have turned up in deserts than in Antarctica. Dealers and collectors worldwide quickly buy them up; so, as with the Mars rocks, lunar meteorites have prices that are truly astronomical — $2,500 to $3,000 per gram.

Iron meteorites are the most sought-after by beginning collectors. Irons tend to meet the expectations of what novice collectors think a meteorite should look like: dark, heavy, and full of holes. Fortunately, there are many iron meteorites available today at modest prices. The Gibeon irons from Great Nama Land, Namibia, are among the finest of the known irons. They are especially beautiful when etched to bring out their internal structure, and they don't rust easily if kept in dry enclosures.

But without question, the Sikhote-Alin irons are the most aesthetically pleasing. Their exteriors show numerous indentations and cavities, probably produced by partial melting during their atmospheric passage. These meteorites fell in the Sikhote-Alin Mountains east of Iman, Siberia, Russia, February 12, 1947. One object fragmented into thousands of pieces, many of which produced craters on impact. You haven't begun collecting meteorites until you have at least a 1-pound (0.45 kilogram) specimen to call your own.



THIS CHONDRULE close-up shows bright, colorful olivine crystals make up most of the interior. At least four groups of parallel crystals give this chondrule an hourglass appearance.

Perhaps the most interesting iron meteorite is one we can all see, but cannot touch. Dubbed Heat Shield Rock, it's just sitting on the surface of Mars near the heat shield of NASA's Mars Exploration Rover Opportunity. It's the first meteorite ever discovered resting on another world. Heat Shield Rock sits there as if to tease collector and scientist alike.

Into the field

As you get deeper into meteorite collecting, you may decide to try your luck in the field. If so, here are a few things to keep in mind. Meteorites don't usually arrive on Earth in one piece, and even those that do may break into dozens of pieces on impact.

If you find several meteorites in a specific location, they're likely pieces of the same meteorite. Often, however, meteorites break up as entry forces tear them apart miles above Earth. These pieces will be scattered over a wide area, perhaps over dozens of miles. The more massive fragments have greater momentum and, therefore, travel farther than smaller ones. In all, the fragments striking Earth fall over an ellipse-shape region called a strewn field.

Plots of meteorites recovered from a strewn field can be helpful in locating additional pieces. If the strewn field is old, say, 10,000 to 15,000 years, stone meteorites will have heavy weathering, especially along fractures. A thick covering of oxides may have replaced their telltale fusion crusts, the dark layer acquired as a meteorite's surface melts during its fall — this makes spotting them difficult. Virtually all chondritic meteorites contain 2- to 10-percent nickel-iron alloy — enough to make a metal detector scream and strongly attract a magnet.

There are two ways to start a meteorite collection: the slow way and the fast way. You can spend your weekends roaming the countryside looking for meteorites in known strewn fields — or you can spend hundreds, even thousands, of dollars acquiring them through cash or trades, wheeling and dealing in the meteorite marketplace. Whichever way you choose, you'll be rewarded every time you hold your own piece of the solar system in your hand.

O. Richard Norton *is the author of* The Cambridge Encyclopedia of Meteorites *(Cambridge University Press, 2002) and* Rocks from Space: Meteorites and Meteorite Hunters *(Mountain Press Publishing, 1998).*

ONLINE EXTRA A meteorite scientist shares his experience buying specimens on eBay at www.astronomy.com/toc.

STONY-IRON METEORITES

Rock-metal fusion

The rarest class of meteorites also is the most beautiful. /// BY MICHAEL E. BAKICH

All meteorites can be classified as rare, but stony-irons are the rarest. These oddballs form at the interface of an asteroid's metallic core and rocky mantle.

In space, stony-irons make up about 1 percent of all meteoroids. Likewise, on Earth, about 1 percent of all meteorite finds are stony-irons. These metal-rock mixtures are easy to recognize. No earthly mineral, ore, or mixture looks anything like a stony-iron meteorite. ▲

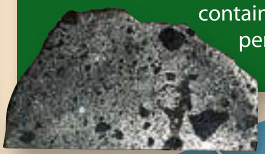
MAP: NASA'S EARTH OBSERVATORY/FRANCIS REDDY/*ASTRONOMY*: ROEN KELLY

ALL METEORITE IMAGES: ROBERT HAAG

Emery (South Dakota)

Mesosiderite — 205 grams

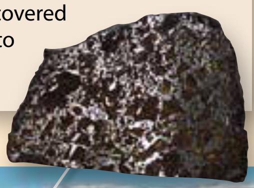
In 1962, a 12-year-old farm boy was breaking rocks on a pile. When one of the rocks — a "black stone" — proved much heavier than the others, he took it home. In 1968, tests showed it to be a meteorite. The iron in this meteorite contains 7-percent nickel.



Admire (Kansas)

Pallasite — 400g

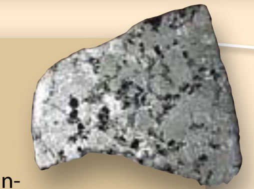
Like many meteorites, the Admire pallasite was unrecognized as a meteorite for years. A farmer discovered an unusual 6-kilogram rock in 1881, but it wasn't until 1962 that it "became" a meteorite. Further searches increased the total recovered weight to 80 kg.

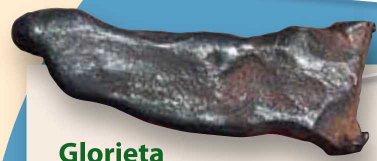


Vermillion (Kansas)

Pallasite — 794g

A farmer found a single 34.4-kilogram mass of this stony-iron while planting in a grain field. Vermillion classifies as a pyroxene pallasite, or iron with silicate inclusions. The meteorite contains 86-percent metal (7.5 percent of which is nickel) and 14-percent silicates.





Glorieta (New Mexico)

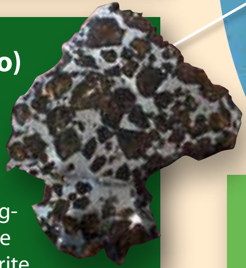
Anomalous pallasite — 35g

In May 1884, explorers found the first fragments of this meteorite on a farm 5 miles south of Glorieta Mountain. Many smaller pieces are 100-percent iron (and are known as siderites). They flaked off during the meteorite's atmospheric entry.

Dora (New Mexico)

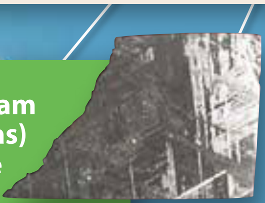
Pallasite — 161g

Discovered in 1955, the Dora stony-iron sat by a fence for 11 years before it was recognized as a meteorite. The outer skin of the meteorite exhibited fusion crust — burning caused by the fiery atmospheric passage. The metal contains 11.7-percent nickel.



Brenham (Kansas)

Pallasite

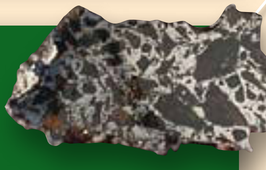


— Etched slice of iron content

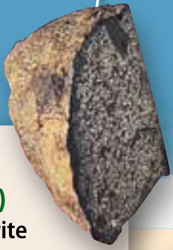
The first fragments of this meteorite were found in 1882. Since then, more have been found including, in October 2005, the largest pallasite ever found in the United States — 636 kilograms. The cut specimen shown above has no olivine — only metal.

Otinapa (Mexico)

Pallasite — 2.5 kg



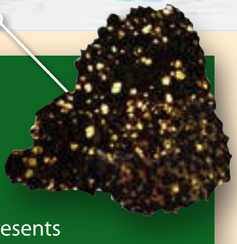
A single 8.4-kilogram specimen of this stony-iron meteorite was found in 1986. The polished face reveals large, angular olivine crystals. The metal contains 10.6-percent nickel and 0.5-percent cobalt.



Lamont (Kansas)

Mesosiderite — 3.8 kg

In 1940, a farmer discovered a single 38.7-kilogram piece among stones in a fence row. The farmer used the rock for years to hold down a tarp on a tractor. The Lamont mesosiderite is olivine-rich but rusts easily.



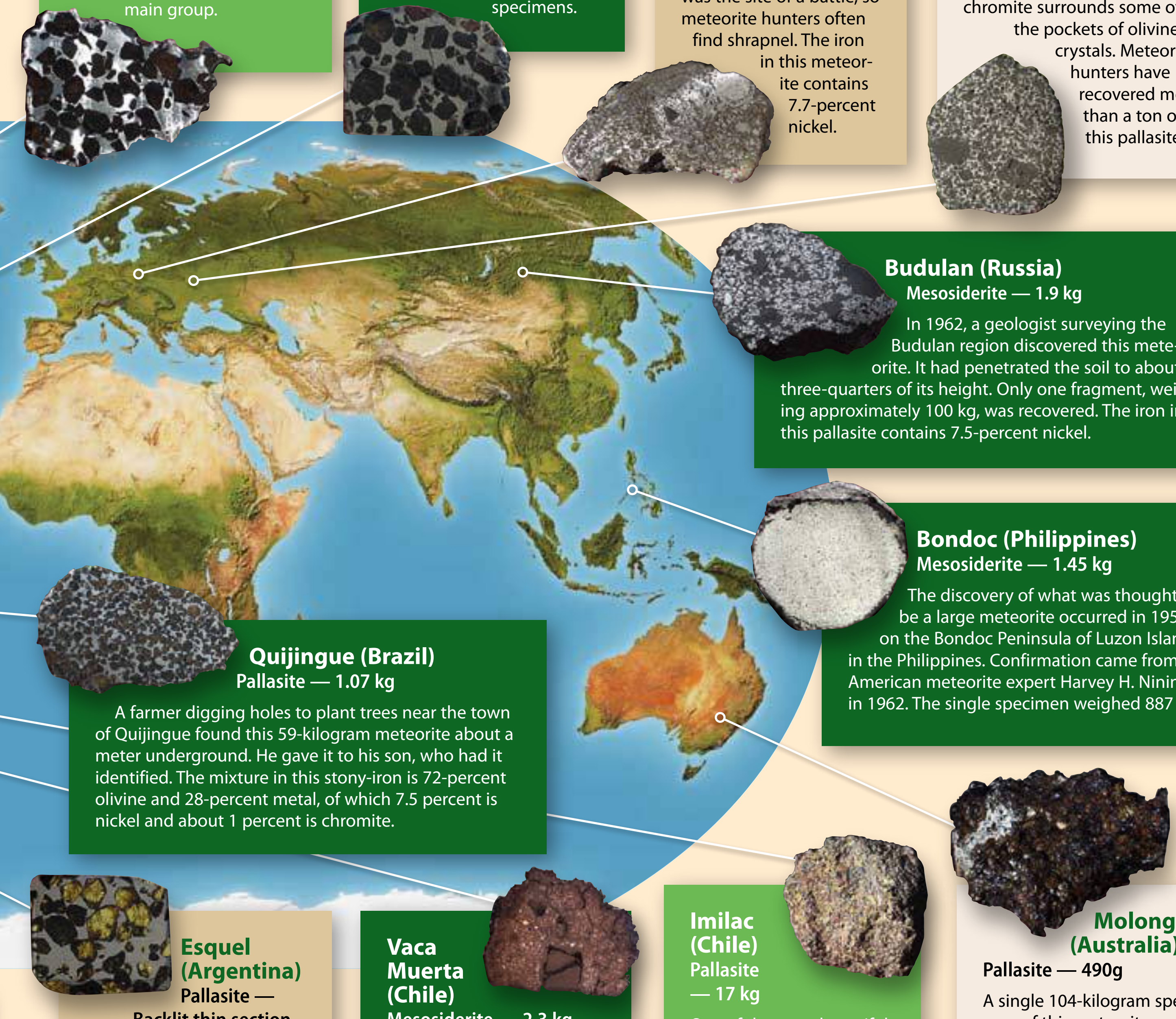
Thiel Mountains (Antarctica)

Pallasite — 310g

This meteorite represents one of the earliest Antarctic meteorite finds. Explorers discovered two specimens (22.7 kg and 9.0 kg) on a glacier's surface in the vicinity of Mt. Wrather in January 1962.

Astronomy magazine

1 gram = 0.035 ounce
1 kilogram = 2.2 pounds
1 kilometer = 0.62 mile



South Bend (Indiana)

Main group pallasite — 126g

Discovered in 1893, all specimens of this meteorite come from a single 2.5-kilogram piece uncovered by a plow a few miles from town. Two groups of pallasites exist, the main group and the Eagle Station trio. The latter contains just three members with different compositions than the main group.

Ahumada (Mexico)

Pallasite — 295g

In 1909, this meteorite — a single 52.6-kilogram specimen — was found in the state of Chihuahua. The Ahumada pallasite is noteworthy because of its large, dark olivine crystals. Some yellow-orange peridot crystals also appear in certain specimens.

Lowicz (Poland)

Mesosiderite — 979g

At around 1 A.M. on March 12, 1935, 58 stones — weighing a total of 59 kg — fell between the Polish towns of Seligow and Krempa. The area was the site of a battle, so meteorite hunters often find shrapnel. The iron in this meteorite contains 7.7-percent nickel.

Brahin (Belarus)

Pallasite — 8 kilograms

Fragments of this pallasite were first discovered in 1810, and more were found as recently as 1968. In this meteorite, and in the Brenham (Kansas) pallasite, chromite surrounds some of the pockets of olivine crystals. Meteorite hunters have recovered more than a ton of this pallasite.

Budulan (Russia)

Mesosiderite — 1.9 kg

In 1962, a geologist surveying the Budulan region discovered this meteorite. It had penetrated the soil to about three-quarters of its height. Only one fragment, weighing approximately 100 kg, was recovered. The iron in this pallasite contains 7.5-percent nickel.

Bondoc (Philippines)

Mesosiderite — 1.45 kg

The discovery of what was thought to be a large meteorite occurred in 1956 on the Bondoc Peninsula of Luzon Island in the Philippines. Confirmation came from American meteorite expert Harvey H. Nininger in 1962. The single specimen weighed 887 kg.

Quijingue (Brazil)

Pallasite — 1.07 kg

A farmer digging holes to plant trees near the town of Quijingue found this 59-kilogram meteorite about a meter underground. He gave it to his son, who had it identified. The mixture in this stony-iron is 72-percent olivine and 28-percent metal, of which 7.5 percent is nickel and about 1 percent is chromite.

Esquel (Argentina)

Pallasite — Backlit thin section

A single 1,500-kilogram fragment of this meteorite was discovered in 1951. The Esquel stony-iron has the best gem-quality peridot of any meteorite. This pallasite also is the most stable, rusting slowly and almost never separating into its component parts.

Vaca Muerta (Chile)

Mesosiderite — 2.3 kg

First discovered in Chile's Atacama Desert in 1861, the Vaca Muerta stony-iron contains roughly 10-percent silicate and eucrite inclusions. Note the large, achondrite-like stony nugget in the above image. The metal of this meteorite is 7- percent nickel.

Imilac (Chile)

Pallasite — 17 kg

One of the most beautiful of pallasites, the Imilac stony-iron was discovered by western explorers in 1822 in Chile's Atacama Desert. It was known to natives prior to that date. The metal contains 9.9-percent nickel, as well as trace amounts of gallium, germanium, and iridium.

Molong (Australia)

Pallasite — 490g

A single 104-kilogram specimen of this meteorite was discovered in 1912 near Ti Tree Creek in New South Wales. This pallasite is almost all olivine crystals. Between them runs a thin metal layer. The olivine contains sufficiently low iron (9.6-percent iron oxide) to qualify as peridot. The Molong pallasite's metal is 9-percent nickel.

The Perseid meteor shower is one of amateur astronomy's great yearly social events. /// BY MICHAEL E. BAKICH

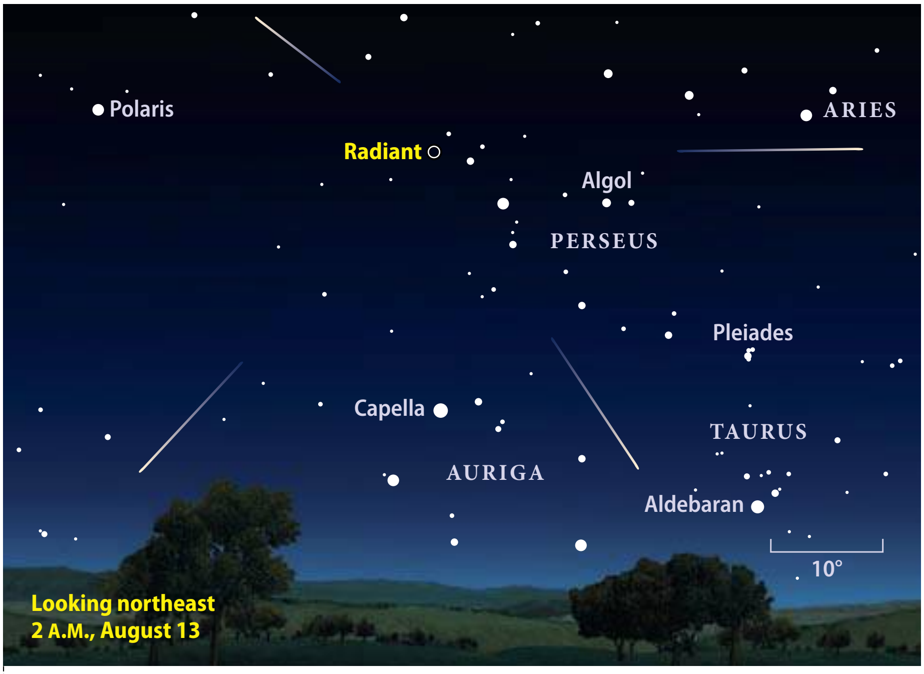
Party with the Perseids!

Here's the good news: It's time once again for the annual Perseid meteor shower, typically the greatest shower of the year. This event occurs during summer, so many people not usually considered astronomers venture outdoors to watch it. As a bonus, this year's peak falls on a Saturday evening for North American observers.

Here's the bad news: The Moon will shine brightly, only 3 days past its full phase. It rises about 2 hours after sunset and is more than 80-percent illuminated, so its light, scattered through the sky, will prevent observers from seeing faint meteors. But don't write off this year's Perseids. Typically, this shower features a high hourly count with lots of bright meteors. In addition, many leave luminous trails visible for several seconds.

For many amateur astronomers, however, the Perseids' real treat lies in getting together with like-minded friends and having a fun night under the stars. Few astronomical sights have the drama of a brilliant fireball (a meteor that casts a shadow) or bolide (an exploding meteor), and meteor showers hold the potential for such events. Also, the excitement level rises if you experience a bright meteor with a group.

Most astronomy clubs host observing sessions either on the night of the shower's predicted maximum or on a weekend night closest to it. If you're not doing serious meteor counting, all you'll need to bring is a lawn chair, some snacks, and your eyes. Binoculars and telescopes do a great job of magnifying objects, but they severely restrict the field of view, a negative for meteor watching.



ALL PERSEID METEORS originate from a point near the top of the constellation. To see the maximum number of meteors, look roughly 30° away from the radiant. *ASTRONOMY*: ROEN KELLY

What's going on?

Meteors are small particles of rock and metal that Earth runs into as it orbits the Sun. Astronomers call these space-based particles meteoroids. When they burn up in the atmosphere, the bright streaks they produce become meteors. If they survive the fiery ordeal of passage through our thick blanket of air, they are then known as meteorites. No meteorites come from meteor showers — the particles are too small.

All meteor showers originate with comets. When a comet swings around the Sun, our star's heat boils off ice and, with it, trapped debris. When the debris trail's orbit crosses Earth's orbit, we experience a meteor shower.

The Perseids' parent comet is 109/P Swift-Tuttle. Lewis Swift of Marathon, New York, and Horace Tuttle, who worked at Harvard Observatory, Massachusetts, each discovered the comet in July 1862. It shone at magnitude 7.5 at discovery and brightened to about magnitude 2 by early September. It sported a tail between 25° and 30° long and was quite impressive. The comet visits our part of the solar system about every 120 years. In November 1992, it brightened to 5th magnitude.

By the way, we call this particular shower the Perseids because, if you trace all of the meteor trails backward, they meet within the boundaries of the constellation Perseus the Hero.

Michael E. Bakich *is a senior editor of* Astronomy.

PHOTOGRAPHING METEORS takes patience. Amateur astronomer Michael Kobusch used an all-sky camera with a Zodiak 30mm f/3.5 fisheye lens (set at full aperture) to capture the 1993 Perseid meteor shower. The picture above is a 1-hour exposure taken August 11/12, 1993. Two Perseids appear at the top, cutting across the star trails. The bright light at the lower right is the rising Moon.

2006 forecast

The Perseids will peak around 6 P.M. EDT August 12th — a Saturday! This is a real plus for getting friends and family — not to mention astronomy-club members who work during the week — out to the show.

August 12 isn't the only date to observe Perseid meteors. This year, the shower will be active between about July 30 and August 25. Of course, you'll see fewer meteors the farther you observe from the peak.

Early in the evening on August 12, set up a lawn chair, preferably one that reclines. Face east, and look a third to half of the way up in the sky. After the Moon rises, adjust your chair so it faces away from the Moon and you can generally look overhead. The Moon will move into the western sky as the peak approaches. When the Moon's disk enters your field of view (around 2 A.M. local time), turn your chair back to the east and concentrate on an area of sky about halfway up. Glancing around won't hurt anything.

Let those around you know when and where you spot a bright Perseid. Some meteor trails last for several seconds, and glowing trains may remain long after the meteors' light fades.

How many Perseids will you see? Meteor counters use a quantity called the Zenithal Hourly Rate (ZHR). This is the number of meteors visible per hour for an observer under a dark sky with no scattered light and with the radiant (the meteors' origin point) positioned directly overhead. The ZHR for the Perseids is 110. This year, with a bright Moon in the sky, you can expect to count between 20 and 30 meteors per hour — still not a bad rate.

All meteor showers are fun events, but summer's Perseids rank at the top. Be comfortable, have fun, and get ready for some "oohs" and "aahs." A

ROCKS AROUND THE CLOCK TONIGHT

- To be visible, a meteor must be less than 120 miles (200 kilometers) from you.
- Meteors become visible at an average height of 55 miles (90 km). Nearly all burn up before they reach an altitude of 50 miles (80 km).
- No shower meteor has survived its flight through the atmosphere and been recovered as a meteorite.
- The typical bright meteor is produced by a particle no larger than a pea with a mass less than 1 gram.
- The average total mass of meteoritic material entering Earth's atmosphere is estimated to be between 100 and 1,000 tons (91,000 and 910,000 kilograms) per day.
- The typical hourly rate for meteors on a "non-shower" night is approximately 6. Astronomers call these random streaks sporadic meteors.
- A meteoroid enters the atmosphere at a velocity between 360 and 2,750 mph (800–6,000 km/hr).

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Left to right: **Astro-Tech** AT66ED, $329; AT80, $379; AT80ED, $529

Not only a veritable plethora, but a whole bunch! Compact fast focal ratio refractors in the 60mm to 80mm aperture range have become all the rage lately as the prices of premium apochromatic (color-free) optics have dropped to affordable levels.

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Astro-Tech AT-80: 80mm f/6 achromat, rotating dual-speed Crayford focuser, choice of four colors, soft case .... 379^{00}

Astro-Tech AT-80ED: 80mm f/6.9 ED apochromat, rotating dual-speed Crayford focuser, choice of two colors, equatorial dovetail, hard case .... 529^{00}

Celestron 80ED: 80mm f/7.5 ED optics, 6 x 30mm finder, rack and pinion focuser, 25mm Plössl eyepiece, image-erecting diagonal, equatorial dovetail .... 409^{95}

Celestron Onyx: 80mm f/6.25 ED optics, rotating Crayford focuser, peep-sight finder, equatorial dovetail, hard case .... 699^{00}

Meade 80mm ED Triplet: 80mm f/6 ED triplet apochromat, adjustable lens cell, Crayford focuser, hard case .... 599^{00}

Meade 80mm ED Triplet package: 80mm f/6 ED triplet apochromat, adjustable lens cell, Crayford focuser, 2" dielectric diagonal, hard case .... 699^{00}

Takahashi FS-60C: 60mm f/5.9 fluorite apo, rack and pinion focuser .... 829^{00}

TeleVue TV-60: 60mm f/6 SD apochromat, two-stage focuser (drawtube plus helical fine focus), soft case .... 825^{00}

TeleVue TV-76: 76mm f/6.3 SD apochromat, rack and pinion focuser, choice of two colors, soft case .... 1320^{00}

TeleVue TV-76 package: 76mm f/6.3 SD apochromat, rack and pinion, 20mm Plössl, 2" Everbrite diagonal, choice of two colors, soft case .... 1725^{00}

Vixen A80SSWT: 80mm f/5 achromat, rack and pinion focuser, flip mirror 1.25" diagonal, red dot finder, equatorial dovetail .... 399^{00}

William Optics ZenithStar 66: 66mm f/6.1 four-element ED semi-apochromat, rotating dual-speed Crayford focuser, soft case .... 348^{00}

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William Optics ZenithStar 80: 80mm f/6 achromat, rotating dual-speed Crayford focuser, 2" dielectric diagonal, soft case .... 499^{00}

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And now, while quantities last, buy a Coronado PST at its regular price, and you get a Meade electronic eyepiece for free! The $149 list price electronic eyepiece lets you put those fascinating monochrome PST solar images on a TV screen for all to see.

Big binoculars. Bright images. Little prices.

You don't need a telescope to enjoy astronomy. Many deep space sights – nebulas, galaxies, star clusters – are all visible through large aperture binoculars, as are myriad craters, seas, and mountains on the Moon.

$179

The **Meade 9 x 63mm** roof prism, to the right, shows you detailed views of the sky for *very* little cash compared with other roof prisms its size. It has fully multi-coated high transmission BaK-4 prisms.

The big **Celestron 25 x 100mm Skymaster**, below, gathers as much light as two 4" rich field telescopes, one for each eye. The similar but smaller **20 x 80mm Skymaster** at $239, not shown, has the light-gathering of a pair of 3.1" rich field telescopes. Both are serious binos for serious deep space viewing.

$329

> I just wanted to thank you again for the great service. Your prices were as cheap as the others, but your service and willingness to help certainly sealed the deal. It is because of this attitude that Astronomics will definitely get my return business, every time, as well as every referral.
>
> **Customer Quote of the Month #173**

Celestron NexImage captures the solar system for $99.

The $99 **Celestron NexImage** CCD camera takes high power full color images of the Moon and planets with any telescope. It sends them to your computer to view live or print out later. The full color CCD imaging chip in the NexImage has a big 640 x 480 array of 5.4 micron pixels for sharp and clear high-resolution images.

For wider lunar panoramas, the optional $24.50 NexImage Reducer Lens doubles the camera's field of view.

Celestron Dobs are nifty, inexpensive, *and in stock.*

8" f/6 StarHopper

$349

Celestron StarHopper Dobsonians use roller bearings for smooth hitch-free motion at the touch of a finger.

The 6" StarHopper comes with a 6 x 30mm finder, a 1.25" metal rack and pinion focuser, and a 25mm 1.25" Plössl eyepiece.

8", 10", and 12" StarHoppers have a big 9 x 50mm finder, 2" metal rack and pinion focuser (with a 1.25" eyepiece adapter), and a 32mm E-Lux 2" eyepiece. The 10" and 12" scopes have a battery-operated fan for cooling their primary mirrors. All scopes have fast cool-down metal tubes and BK7 optical glass mirrors, and all are in stock for immediate shipment.

Here are the prices for the fully-equipped Celestron StarHopper Dobsonians we stock.

6" f/8 StarHopper	**$249^{00}**	+ $59 freight
8" f/6 StarHopper	**339^{00}**	+ $69 freight
10" f/5 StarHopper	**499^{00}**	+ $79 freight
12" f/5 StarHopper	**849^{00}**	+ $129 freight

12 volt power to the people for only $59^{95}!

You can recharge a **Celestron Power Tank** battery many times, saving you the cost of buying flashlight batteries every few weeks to power your scope. 7 amp hour Power Tanks start at only **$59.95**.

Celestron's SkyScout *tells* you about the sky while it shows you the night's sights.

$399 freight paid

The **Celestron SkyScout** is an award-winning handheld non-magnifying GPS-based personal planetarium that identifies or locates more than 6,000 celestial objects visible to the unaided eye, then tells you their facts and history. Use the SkyScout by itself to learn the legends, myths, and sights of the sky. Or mount it on your telescope to let it guide you from one celestial showpiece to another.

There's a scrolling 5-line display of text and graphics. Supplied earphones let you hear the commentary so you don't have to look away from the sky to read it. Optional speakers let others hear, too.

The SkyScout transforms the night sky into a planetarium for stargazers, families, and students. It makes learning the stories of the sky – *and finding your way around the sky* – easier than ever before.

No-guesswork Celestron *GPS* Schmidt-Cassegrains.

Celestron 8" f/10 CPC800

$1899

It's easy to find your way around the sky with a **Celestron CPC**. Just point it at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet or the Moon), and the CPC will find over 45,000 deep space objects for you at the touch of a button.

You don't have to memorize a star chart to use a CPC. The scope's GPS system and a few anonymous lights in the sky are all you need.

Celestron CPC Schmidt-Cassegrains are fully equipped with all the features you need to start observing immediately.

8" **CPC800**, Starbright multicoatings	...	**$1899^{00}**
8" **CPC800X**, XLT multicoatings	....	**1999^{00}**
9¼" **CPC925**, Starbright multicoatings	..	**2349^{00}**
9¼" **CPC925X**, XLT multicoatings	......	**2499^{00}**
11" **CPC1100**, Starbright multicoatings	.	**2599^{00}**
11" **CPC1100X**, XLT multicoatings	.....	**2799^{00}**

Get a $399 Deep Sky Imager Pro CCD camera for $129 when you buy a Meade telescope.

The **Meade Deep Sky Imager Pro** CCD camera sells for $399. But, through August 31, you can get the DSI Pro for only $129 when you buy a Meade LXD75, LX90, LX200, or RCX400 telescope!

The monochrome DSI Pro is loaded with features like NASA-developed "Drizzle" software that sharpens the resolution and quadruples the size of your LX90, LX200, or RCX400 deep space photos. And the filter set for tri-color imaging, normally $199, is only $99 if bought with camera and scope.

The DSI Pro opens up a whole new way to observe with a Meade telescope. Best of all, you save a total of $370 on the DSI Pro and color filter set when you buy them along with your LXD75, LX90, LX200, or RCX400.

A Telegizmos protects your scope day and night.

A **Telegizmos** scope cover protects your telescope from sun and dew. NASA-developed to insulate spacecraft, these aluminized covers are strong, light, and more durable than Mylar. Prices start at only $29.

Not much cash buys you a lot of Konus.

$209

3.5" f/11 Konus refractor

$499

8" f/5 Konus reflector

6" f/12 Konus Maksutov

$799

The low prices of these **Konus** telescopes are downright amazing.

Consider the optically very nice 90mm **Konusmotor-90** f/11 refractor to the left. It has a good-quality equatorial mount, a battery-powered motor drive so you can use it anywhere, and *two* 1.25" Plössl eyepieces. We sell this scope by the dozens, because it's a great value at only $209!

The **Konusky-200** 8" f/5 reflector, above right, has a heavy duty equatorial mount with a steel leg tripod, *dual-axis* DC motor drives, an 8 x 50mm finderscope, polar axis finder, and *two* 1.25" Plössl eyepieces. This 8" Konus is a big telescope for the little price of only $499!

The **Motormax-150** 6" Maksutov, to the right, has the same heavy duty mount and accessories as the 8" reflector. This 6" Mak is a terrific value at its low price of only $799, which is well below the cost of other large Maksutovs.

Vixen Sphinx go-to is easy as point-and-click.

$2199

Sphinx mount, 1.9kg counterweight, SX HAL110 tripod

The Star Book hand control of the Vixen Sphinx mount makes go-to astronomy easy. Simply move a cursor to an object on the Star Book's 4096-color LCD star chart screen, click on it, and the Sphinx moves to that object. That's it. That's all it takes to find your way around the sky.

As a Vixen stocking dealer, we keep the Sphinx mount in stock for use with your optics or with the premium Vixen optics we stock. It will handle optical tubes from an 80mm refractor up to an 8" reflector or catadioptric scope.

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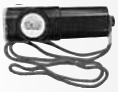

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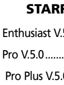

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Name that rock

Astronomy magazine

Scientists classify meteorites by what they're made of and where they come from. /// BY MICHAEL E. BAKICH

ALL METEORITE IMAGES: ROBERT HAAG

Meteorites fall into three general classifications. Stone meteorites have low metal content, originating, as they did, in the outer, stony mantles of asteroids. Iron meteorites are the opposite of stones — they come from asteroids' metallic cores. Stony-iron meteorites form at the transition zone, which contains both metal and rock.

Beyond these three classifications, however, scientists divide stone, iron, and stony-iron meteorites into many subcategories. Stone meteorites fall into either of two classes: chondrites or achondrites. Stony-irons divide into mesosiderites and pallasites. Iron meteorites have three structural subgroups (ataxites, hexahedrites, and octahedrites) and any of 14 chemical subgroups, which meteoriticists base on the ratios of certain chemical elements. A

THE CAMEL DONGA (Australia) stone meteorite (eucrite achondrite) has an unusually high iron content of 2 percent. The shiny crust indicates a calcium-rich specimen.

STONE	Achondrites	Primitive	Acapulcoite	
			Brachinite	
			Lodranite	
			Ureilite	Main group
				Polymict
			Winonaite	
		Evolved	Angrite	
			Aubrite	
		HED group	Howardite	
			Eucrite	Non-cumulative (originated in asteroid 4 Vesta's upper crust)
				Cumulative (originated in Vesta's magma chambers)
				Polymict (breccias with 90-percent eucritic material and 10-percent diogenitic material)
			Diogenite	
		Martian	SNC	Shergottite
				Nakhlite
				Chassignite
			Orthopyroxenite	
		Lunar	LUN A	
			LUN B	
			LUN G (gabbro)	
			LUN N (norite)	
	Chondrites	Ordinary	Amphoterites (LL group) — low total-iron content; low metallic-iron content	
			Olivine-bronzites (H group) — high total-iron content	
			Olivine-hypersthenes (L group) — low total-iron content	
		Carbonaceous	CH	
			CI	
			CK	
			CM	
			CO	
			CR	
			CV	
		Enstatites (E group)	EH (high iron content)	
			EL (low iron content)	
		Forsterites (F group)		
		Kankagariites (K group)		
		Rumurutiites (R group)		

DAR AL GANI 400 (Libya) originated on the Moon. Classified as an achondrite stone meteorite, it was found March 10, 1998.

IRON

Chemical classifications

IAB
IC
IIAB
IIC
IID
IIE
IIF
IIG
IIIAB
IIICD
IIIE
IIIF
IVA
IVB

Meteoriticists base this classification scheme on the abundance of nickel to gallium, germanium, and iridium. As the numbers increase (down the scale), so does the ratio of nickel to these three elements.

Structural classifications

Ataxites	Nickel-poor (less than 6-percent nickel)		All ataxites belong to chemical classification IIICD. They have no internal structure (no Widmänstatten lines).
	Nickel-rich (more than 11-percent nickel)		
Hexahedrites	These meteorites contain roughly 92 percent of the mineral kamacite; named for kamacite's six-sided (hexahedral) cleavage; total nickel content between 4.5 and 6.5 percent. All hexahedrites belong to chemical classification IIAB. Widmanstätten bands are wide (>50mm) and may not be visible in small specimens.		
Octahedrites	Named because of the way taenite and kamacite plates arrange parallel to the eight triangular faces of an octahedron.		
	Mean width of kamacite layers		Chemical classification subgroups
	Coarsest (Ogg)	greater than 3.3 millimeters	IIAB, IIIF
	Coarse (Og)	1.3mm to 3.3mm	IAB, IC, IIE, IIIAB, IIIE, IIIF
	Medium (Om)	0.5mm to 1.3mm	IAB, IID, IIE, IIIAB, IIIF
	Fine (Of)	0.2mm to 0.5mm	IID, IIICD, IIIF, IVA
	Finest (Off)	less than 0.2mm (layers are continuous)	IIC, IIICD
	Plessitic (Opl)	less than 0.2mm (layers form spindles)	IIC

STONY-IRON

Pallasites

Composition

Main group	iron, olivine
Eagle Station	iron, olivine, pyroxene
Pyroxene grouplet	iron, pyroxene

Mesosiderites

Metamorphic grade

Class A (basaltic)	1A	Key: 1= fine-grained, fragmented; 2 = some recrystallization; 3 = much recrystallization; 4 = melted breccia
	2A	
	3A	
	4A	
Class B (ultramafic)	1B	
	2B	
	3B	
Class C (orthopyroxene)	2C	

THE SANTA CLARA (Mexico) iron meteorite is a nickel-rich ataxite. It contains more than 16-percent nickel.

THE SANTA ROSALITA pallasite fell in Mexico. It is 75-percent olivine, and its iron contains 11.7-percent nickel.

Meteorite dealer Robert Haag travels the world in search of space rocks. /// **BY RAYMOND SHUBINSKI**

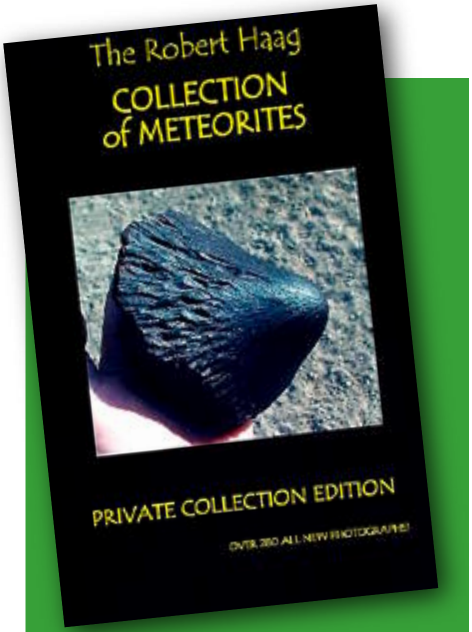
Rock star

METEORITE DEALER **Robert Haag poses like a rock star by using a large slab of the Esquel pallasite meteorite as a mock guitar. In addition to the meteorites he's sold, Haag's personal collection contains many such standout specimens.**

ALL PHOTOS: *ASTRONOMY*: MICHAEL E. BAKICH, UNLESS NOTED

What do you get if you cross Indiana Jones with a rock star? My answer would be Robert Haag, a guy who collects and sells meteorites. Haag, 40, from Tucson, Arizona, is a real-life meteorite expert who has made it big in rock-hunting. More than 2 decades ago, he began pursuing space rocks, venturing to some of the most remote locations on Earth.

Haag's interest in meteorites hearkens back to a family vacation in Mexico. While sitting under a dark desert sky, he saw a brilliant fireball. He was convinced a meteorite from the event had fallen in the hills just beyond his view, and a lifetime of searching for such objects began.



HAAG'S LATEST CATALOG, published in 2003, marks the 13th edition of this landmark. Its 128 pages contain lots of information on meteorites, each of which is in Haag's collection. To order the catalog, visit www.meteoriteman.com/fieldguide.html. *ASTRONOMY*: WILLIAM ZUBACK

Early inspiration

Haag earned his private pilot's license when he was 21. He keeps an ultralight parked in his garage to this day. His flying skills have proven useful in his never-ending pursuit of space rocks.

But Haag's family had long been involved in the mineral trade. His grandparents owned a rock shop in Tucson, and his parents and Haag's brother worked the business with them. But Haag's love of flying and fascination for meteorites, certain kinds of rocks — ones that fell from the sky — sent him on a different path.

The space-rock business

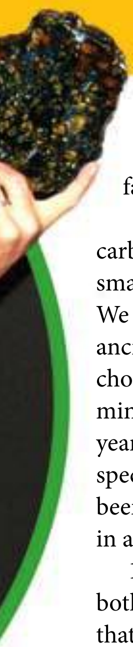
I met Haag in the fall of 1985. At our first meeting, he talked about a trip to Egypt in search of specimens of the Nakhla meteorite, which fell in 1911. Here was a guy casually showing me photos from his "field trip" to the Middle East and explaining difficulties he encountered as if it had been an excursion to New York City. "The problem was my total lack of Arabic," explained Haag. "This was still during the Cold War, and everyone thought I was an American spy there to steal their children."

Around that time, Haag began participating in the massive Tucson Gem and Mineral Show, which is one of the biggest such events in the world. Thousands of rock, fossil, and meteorite collectors from around the world visit the show on an annual basis.

Haag's participation was a hit. Soon, prospective buyers hailed him as one of the world's top meteorite dealers. His room offered more than sales. There, merchants, adventurers, scientists, and the curious gathered to swap stories and meteorites. The stories were intoxicating, and the atmosphere was thick with excitement over these rusted rocks.

Haag continued to travel — he'd disappear and then reappear with new treasures. He made repeated trips into Mexico to recover what seemed to be mountains of meteorites. In 1980, Haag recovered more

Raymond Shubinski *is the director of Science City/Attractions in Kansas City, Missouri, and an ardent meteorite collector.*



than 110 pounds (50 kilograms) of the famous Allende meteorite.

In 1969, several tons of a rare type of carbonaceous chondrite peppered the small town of Allende, Chihuahua, Mexico. We now know the Allende meteorite is ancient. Its black interior contains white chondrules identified as calcium and aluminum inclusions that formed 100 million years before Earth. One 37-pound (17 kg) specimen of Allende Haag recovered had been used to block up cars for tire changes in a local garage.

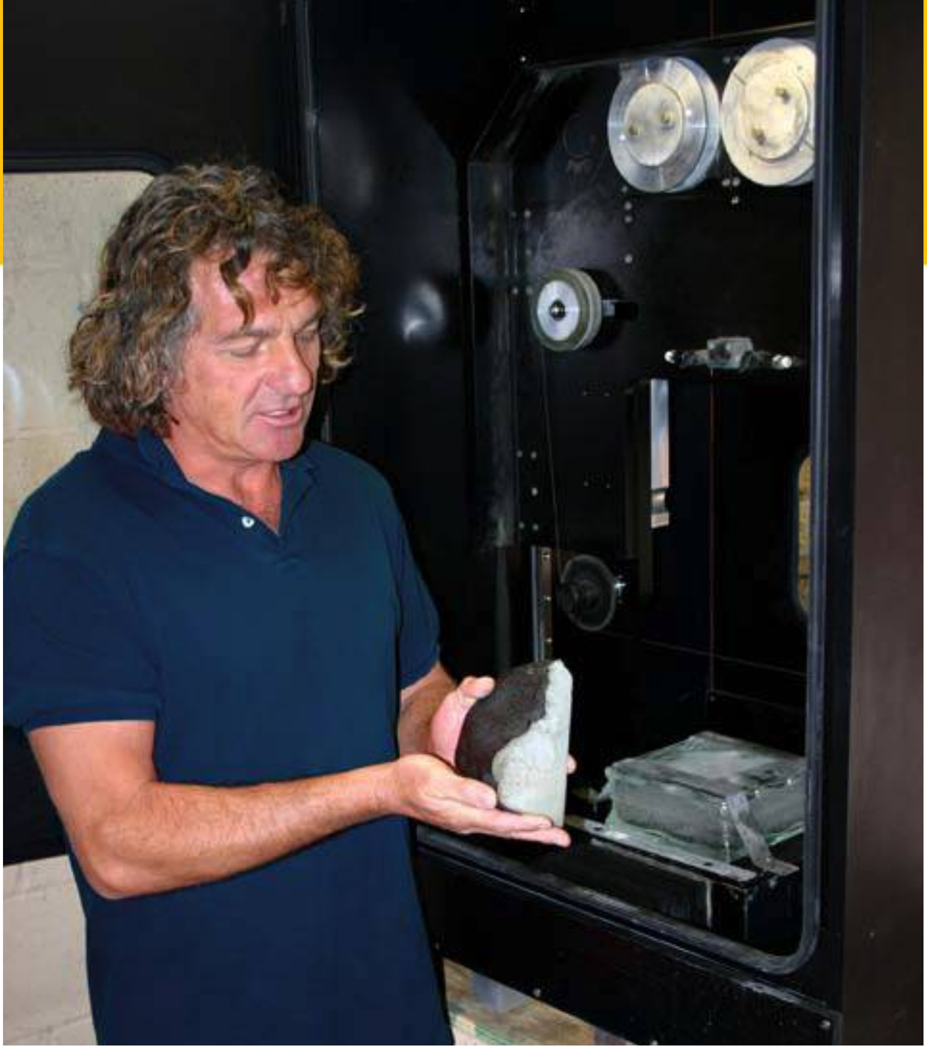
1969 was a busy year for space travel, both incoming and outgoing. Not only was that the year Apollo 11 landed on the Moon and when the Allende meteorite fell, but also when a surprising meteorite fell on the city of Murchison, Australia.

On a Sunday morning in September, residents heard booming and hissing sounds accompanied by an explosion. Shortly thereafter, more than 1,540 pounds (700 kg) of meteorites fell on the area. The fall also produced a strong smell of methylated spirits — something repeated at no other meteorite fall.

More than a decade later, Haag journeyed Down Under to visit the site and collect specimens. While there, he met Betty Maslin, who had witnessed the fall and had kept a piece of the Murchison meteorite in a jar. “When she opened the jar and I took a whiff, the smell almost knocked me off my feet,” says Haag.

No Australian adventure was more memorable than Haag’s trip to the great Nullarbor Plain. Situated in southwest Australia, the Nullarbor is a desert about as remote as any on Earth and home to the Mundrabilla strewn field.

Some meteorites scatter in strewn fields because after they enter Earth’s atmosphere and descend to about 5 miles (8 km) above the surface, they encounter buildups of pressure that shatter them. The pieces hit Earth’s surface like cosmic shotgun blasts producing strewn fields of meteorites. Some strewn fields — such as the 150-square-kilometer one produced by the Allende fall — are enormous.



HAAG STANDS in front of his meteorite-cutting saw, which employs a kilometer-long, diamond-encrusted wire, allowing him to produce extremely thin slices. In his hands, Haag holds the main mass (the largest existing piece) of the Zagami martian meteorite.

TUCSON’S GEM AND MINERAL SHOW offers Haag an opportunity each year to set up display cases filled with meteorites. Here, author Raymond Shubinski (left) and *Astronomy* Editor David J. Eicher (right) check out one of Haag’s latest acquisitions.

IN ADDITION to selling meteorites, Haag provides specimens for scientific study, trades samples to museums, and provides meteorite-related information. Here, he personalizes his latest catalog for a customer.

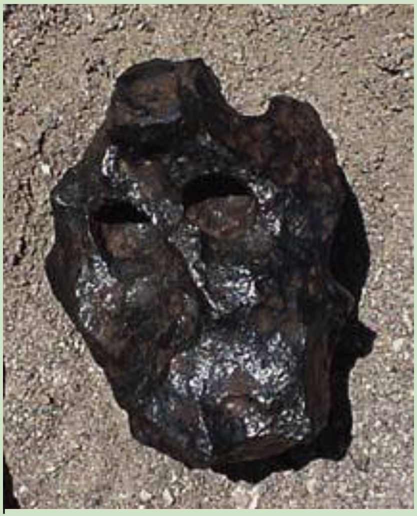
THE "METEORITE MAN"

One iron meteorite — part of the meteorite that formed Meteor Crater, Arizona — has two eyelike depressions, which give it an eerily human look. After spending 3.5 billion years or so floating around the solar system, the meteorite finally "landed" in Robert Haag's vault.

After a few years, Haag negotiated a deal with a collector in the Far East, and the so-called Meteorite Man traveled to Singapore. But other collectors also had their sights set on this unique specimen. Soon, the Meteorite Man was on its way to a collection in Johannesburg, South Africa.

As if the Meteorite Man had a bit of wanderlust, South Africa was not this specimen's final home. A meteorite enthusiast in London swayed the Johannesburg collector, and the Meteorite Man was on the road again.

Like a fickle lover, the London collector moved on, and the meteorite was on the market again. This time the buyer was none other than Robert Haag. After many years of earthly travel, the Meteorite Man is back in Tucson. It's still for sale, and Haag will include a genuine Space Passport. — *R. S.*



THE METEORITE MAN is a fragment of the Canyon Diablo meteorite. ROBERT HAAG

Mundrabilla is an iron meteorite, but the Nullarbor Plain is so dry, the fragments weather slowly, making this a great hunting ground — if you can get there.

Haag and some friends began their journey in Perth, where they bought all the provisions and supplies they'd need for a month. Among the gear was a paraplane. Haag uses such planes to make low-altitude searches for small impact craters.

The Nullarbor proved to be a formidable foe. On one occasion, Haag set off by himself with a metal detector in hand and headphones on his ears. He was having a wonderful time hunting meteorites for 2 hours until he realized he had no idea where he was. On the wide, featureless Nullarbor Plain, getting your bearings is almost impossible. After several more hours of searching for landmarks or anything else that looked familiar, Haag finally turned and started to walk toward the setting Sun. Fortunately, his instinct was right, and he made his way back to camp.

Career benchmarks

Along with his many adventures, Haag defines his career by two meteorite acquisitions and one unbelievable find he made in his own home. On one of my visits during 1988, Haag asked with his impish smile if I'd like to see his new acquisition, and then he handed me the main mass of the Zagami meteorite. At the time, this was one of the few known martian meteorites.

The Zagami meteorite fell in Nigeria near Zagami Rock in 1962, and the piece Haag purchased from one of the original finders is the largest fragment. Currently, Zagami sells for roughly $800 per gram. (Compare that to gold, which, on today's market, sells for less than $25 per gram.)

Meteorite collectors rate pallasites the most beautiful class of meteorites. A pallasite represents a mixture of magnesium-rich olivine and iron. Of this rare class, the finest example is the Esquel pallasite. A single mass weighing more than 3,000 pounds (1,500 kg) was found in Argentina in 1951. Haag was able to secure the meteorite's main mass in 1992.

This was an important find because of the pallasite's stability. The mixture of iron and olivine means moisture can permeate the meteorite's interior, quickly leading to oxidation and deterioration. Most pallasite specimens are in poor condition by the time they're found. The Esquel is so well preserved that the olivine is considered gem quality and has been cut into emerald-like stones by jewelers. Zagami and Esquel not only represent financial high marks for a dealer such as Haag, but collecting "highs" hard to surpass.

True to Haag's nature, he outdid even these collecting accomplishments. His greatest find was not made in the field but given to him wrapped in a brown cardboard box.

In 1967, the residents of Wiluna, Western Australia, witnessed a brilliant nighttime fireball. Years later, an enterprising Australian went looking for meteorites in the area around Millbillillie Station and began to turn up a number of stone meteorites with fresh fusion crusts.

DISPLAYING A NEW ACQUISITION, Haag stands before one of the display cases that house his collection. "Meteorites are no fun if you can't share them with others," says Haag.

CHLOE HAAG sits atop a 1,200-pound (550 kilogram) meteorite found near Mundrabilla, Australia. Hikers found small samples of the iron mass in 1911. Then, in 1966, meteorite hunters found two pieces weighing 11 and 6 tons, respectively.

The prospector taught the local Aborigines to spot the stones and found even more. Eventually, a box of meteorites from this area made its way to Haag.

As he sorted through these stones, Haag came across a strange one. "When I picked up the 19-gram stone it just felt different," says Haag. The texture, the fusion crust, and even the color were unusual compared to the Millbillillie stones. Some years before, Haag had examined a NASA Apollo lunar specimen at the Japanese Institute of Polar Research. The little stone he held looked similar.

Haag took the meteorite to the Lunar and Planetary Laboratory at the University of Arizona in Tucson, where William V. Boynton and Dolores Hill examined it. The two confirmed Haag's impressions — it was a lunar meteorite.

Haag's chosen business has had its trials and tribulations, however. Once the news broke about a Moon rock from Australia being in private hands in Tucson, the government Down Under was unhappy. It made repeated requests to have the lunar meteorite returned without any regard for compensation. Haag kept the Moon rock. Since then, more lunar meteorites have been discovered and, like other rocks from space, retained by those who found them.

Big rock — big trouble

All great hunters and fishers have a story about the one that got away. In the early 1990s, Haag went to Argentina in search of the "big one." He had identified a 37-ton meteorite on a private farm. He negotiated with the land owner, purchased the monster, and received a bill of sale.

With considerable effort, the prize was loaded on a truck. It wasn't long, though, before the local police force took Haag into custody for making off with a national treasure. Haag spent a week with authorities arguing about who had the rights to this chunk of space debris. Needless to say, the gringo was outnumbered and sent home without the meteorite or his money.

When I asked how he could recover from such a financial blow, Haag's upbeat reply was typical: "The national publicity has been great; the phone hasn't stopped ringing since I got home. Sales are way up."

In 1995, Haag returned to Nakhla, Egypt, hoping to find one more piece of the Red Planet. This time, rather then being greeted with suspicion, crowds overwhelmed him as he handed out flyers.

Still going

Today, Haag is older and wiser, but still unstoppable. His wife handles the bookkeeping, and Haag spends more time with his children. He also remains a driving force in the fraternity of meteorite dealers.

But Robert Haag is more than just a meteorite dealer. He'll tell you the hunt is as important as the find. Haag will sit and talk about meteorites all day, but he always comes back to what really motivates him — the love of space and the dream of being part of the wider cosmos.

He sums it up nicely: "Sitting under a dark desert sky when the Milky Way seems to spread like a blanket from horizon to horizon is the real magic; the meteorites are the frosting on the cake." A

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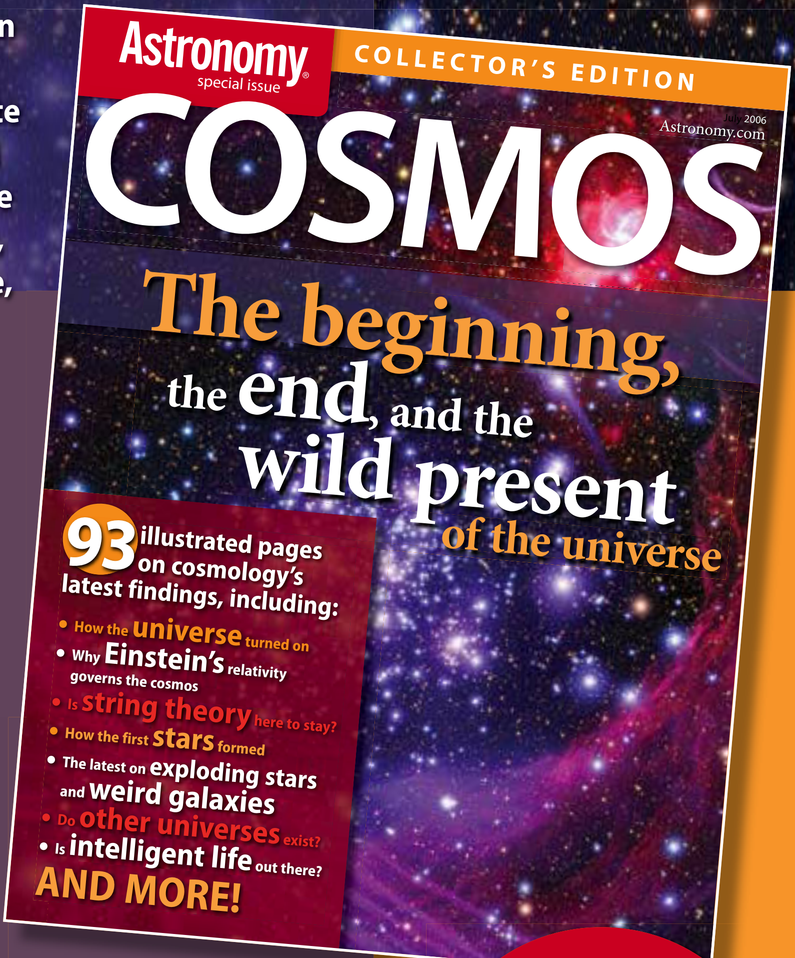

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ASK ASTRO

Astronomy's editors and experts from around the globe answer your questions about the cosmos. This month: recognizing meteorites, detecting exoplanets from wobbles, and do photons have force?

ROCKS FROM SPACE

Q: How can I recognize meteorites among other stones? — **AMIR REZA PEDRAM,** KHORAMABAD, LORESTĀN, IRAN

A: Four major visual clues will help you recognize a meteorite.

- A meteorite usually **attracts a magnet** because it contains metallic iron.
- During a meteorite's plunge through Earth's atmosphere, minerals on the rock's surface melt. Because of this, the meteorite usually has a dark, thin, melted surface layer called a **fusion crust**.
- A meteorite also can have an **aerodynamic shape** acquired during its high-speed flight through Earth's atmosphere.
- A meteorite's surface may be covered with **thumbprint–shaped indentations** called regmaglypts, produced while penetrating the atmosphere.

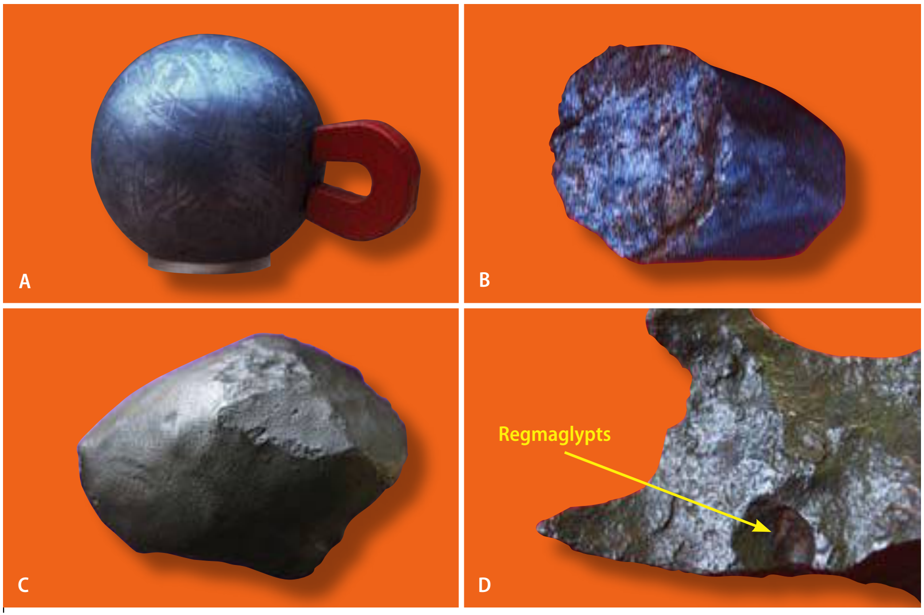
Some meteorites may not exhibit any of these major traits. For example, a stone meteorite weathered by conditions on Earth might not show a fusion crust, aerodynamic shaping, or regmaglypts. And certain types of stone meteorites contain no metal. The more major traits the rock displays, the greater the likelihood it's a genuine meteorite.

Scientists classify meteorites into three categories: irons, stones, and stony irons. Because most meteorites are magnetic, magnetism is always the first test. If the suspect is not magnetic, it is almost always a "meteorwrong." Researchers and collectors quickly learn how to identify an Earth rock from a meteorite because what may be represented as a rare stone meteorite and priced at $200 a gram could turn out to be just an expensive meteorwrong.

Beyond the four visual recognition clues, we can use a simple chemical test for nickel, which is found in high quantities in metal meteorites when compared to terrestrial rocks. By testing for nickel, we can almost always confirm if the suspect is meteoritic. Researchers and collectors may do additional chemical analysis if they think a sample is meteoritic but it does not test positive for nickel.

Sometimes, one must look at the suspect's interior to get a better idea of its origin. Slicing a sample takes a special saw and blade.

While most suspected meteorites turn out to be imposters, occasionally you will find a meteorite. Study specimens at your local museum or college, and read as much as you can on the subject. If possible, buy a few meteorites to study. And, oh yes, buy a magnet. — **MIKE REYNOLDS,** FLORIDA COMMUNITY COLLEGE, JACKSONVILLE



TO RECOGNIZE A METEORITE, look for these four clues: **(A)** a meteorite is usually magnetic, **(B)** it may have a fusion crust, **(C)** possible aerodynamic shape, and **(D)** dime-size indentations. MIKE REYNOLDS

WOBBLE TELLS ALL

Q: How would astronomers in another solar system know by observing our Sun's wobble that our Sun has not just one big planet, but nine, each with a different mass? — **AMY SIMPSON,** VIA E-MAIL

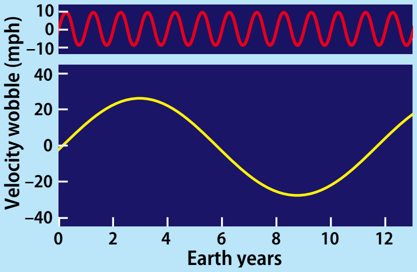
A: As implied, planet-hunters observe the wobbling star rather than the planets themselves. Then, they create a mathematical model to reproduce the observed velocities and predict future velocity signatures. How do we know the mathematical models work for specific systems? Couldn't several planets imitate the signature of a single, more massive planet?

Fortunately, a single planet's signature is distinct from that of multiple planets. Solar systems follow gravity's rules:

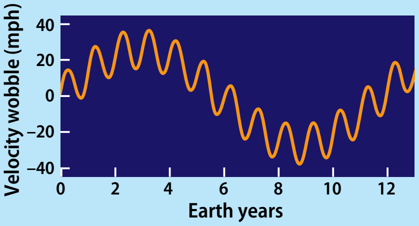
- More massive planets exert a stronger pull on the star — the star will move faster.
- Planets closer to the star exert a stronger pull on it.

DETECTING EXOPLANETS

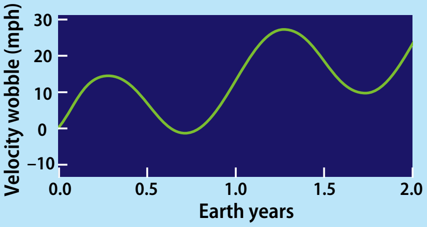
A planet exerts gravitational pull on its star. Astronomers detect exoplanets from a star's Doppler wobble caused by this pull. This is the method astronomers have used to identify most of the exoplanets currently known.



▲ **A 50 EARTH-MASS planet (above, in red) and a Jupiter-size planet (above, in yellow) would create these velocity wobbles over 12 years.**



▲ **WHEN YOU ADD the red and yellow curves together, you get the combined wobble shown above (in orange), which is what astronomers would detect.**



◀ **IF ASTRONOMERS observed the wobble at left (in green), they would know the system has a planet with a period of 1 Earth-year and another with a longer period, because the velocity signature shows an upward trend.**

ASTRONOMY: ROEN KELLY, AFTER DEBRA FISCHER

- The time it takes a planet to complete one orbit increases with distance from the star.
- The star wobbles with the same period as the planet's orbit.

Let's simplify the original question and consider only two planets orbiting the Sun: Earth and Jupiter. Earth would cause a velocity wobble in the Sun of only 0.22 mph (0.36 kilometer/hour) with a 1-year orbital period. Jupiter would cause a 27 mph (43 km/h) wobble, with a 12-year orbital period. State-of-the-art Doppler measurements have a precision of about 2.2 mph (3.6 km/h) — we couldn't even detect Earth. In our example, let's arbitrarily increase Earth's mass by a factor of 50. Its orbital period will still be 1 year, but the Sun's velocity wobble will now be an easily detected 11 mph (18 km/h).

The velocity wobble for the 50 Earth-mass planet and the Jupiter-like planet are shown in the illustrations at the right. The star receives both tugs simultaneously, so what we observe are the added velocities. A 1-year sinusoidal wobble rides on top of a longer-period wave.

We could distinguish a nine-planet system from a single, more massive planet because each planet has a unique orbital period. With a single planet, there is only a single beat — a single wobble. In multiplanet systems, we see a different beat from each planet. If we lived on a planet around a nearby star, and if we had the sensitivity to detect all of the planets orbiting the Sun, then we would know the Sun hosts nine planets (we won't get into a discussion of what constitutes a planet here).

But there's a catch: To model this system, we need to observe at least one full orbit of each planet. Pluto takes 248 years to complete one orbit. Caterpillars move like bullet trains compared to the inch-per-hour Pluto-induced wobble of the Sun. So, mapping out the solar system's architecture would span the career lifetimes of many astronomers and would require velocity-precision measurements technologically beyond our reach.

The final challenge to extreme velocity precision lies in the nature of stars themselves. If you look at movies of the Sun taken with the Solar and Heliospheric Observatory (SOHO), you'll see the Sun's surface convectively boils and flares. We measure the substantial velocities from the surface of our Sun with the same technique we use to find planets orbiting other stars. Stellar surface activity adds noise to our velocity measurements that will ultimately limit our accuracy.

Acoustic modes also cause the Sun to oscillate with periods of a few minutes and are also taken into account. I suspect stellar atmospheres will limit our ability to measure wobble velocities with precisions better than about 1.1 mph (1.8 km/h).

Science is a tag-team sport. By the time planet-hunters using the Doppler-wobble method reach extreme precisions and identify rocky planets at distances similar to Mercury or Venus, NASA will have a fleet of new space missions poised to take the next step. The Kepler mission (scheduled to launch in late 2008) will search distant stars and determine how often earthlike planets occur. The Space Interferometry Mission (scheduled to launch in the next decade) will find rocky planets in the habitable zones around our nearest neighboring stars, and other space missions will aim to image those planets. — **DEBRA FISCHER,** SAN FRANCISCO STATE UNIVERSITY

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Q: I read photons have energy but no mass, so how can massless photons produce a force upon striking a solar sail?

— **EDWARD J. DUGAN III,** CAMAS, WASHINGTON

A: Photons have no mass, but they do have energy, which is proportional to their frequency. We are familiar with this type of energy at various frequencies — microwave ovens are one example, visible light is another. The fact that light has energy is obvious (you can feel the heat).

In the case of solar sails, much of the energy doesn't turn into heat. The sail is reflective, so it absorbs little energy, and, therefore, the light particles bounce off the sail. As they do, they transfer momentum from the light to the sail, producing a force. **This reflective sail gets a double kick: one push from the sail stopping the photon and one from reflecting the photon and accelerating it away.** — **LOUIS FRIEDMAN,** EXECUTIVE DIRECTOR, THE PLANETARY SOCIETY, PASADENA, CALIFORNIA

Send your questions to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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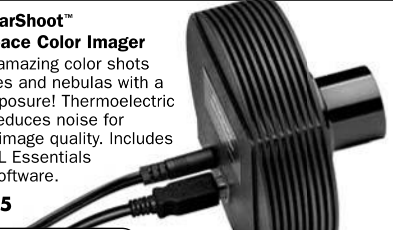

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The Pacific Northwest's most-popular star party is held each summer in the Ochoco National Forest in central Oregon. Since the Oregon Star Party (OSP) launched in 1988, its attendance has exploded to several hundred. ☾ Part of the OSP's success can be attributed to its schedule of activities. In addition to observing, attendees can challenge each other in astronomy quizzes, participate in workshops, and listen to lectures on topics ranging from cosmic distances to the world's great telescopes. Children's activities include telescope mentoring and a remote-controlled Mars rover race.

TOM POLAKIS

THE OREGON STAR PARTY offers numerous activities for children. This year, as with the previous 7, they will race remote-controlled Mars rovers.

The rustic site doesn't provide many amenities. Be prepared to supply your own water and power source.

Astronomy Copy Editor Laura Baird will attend the star party.

For more information, call 503.306.2992; e-mail, ospqa@patch.com; web site, www.oregonstarparty.org.

AUGUST 4–5

Astronomical League Convention (ALCon)

University of Texas at Arlington, Texas. ALCon will feature speakers, programs in the university's new planetarium, a trade show, and awards banquet. For more information, e-mail lindamccalla@yahoo.com or chipdatajeffb@yahoo.com; web site, www.alconexpo.com.

AUGUST 4

Far Out Friday

Adler Planetarium and Astronomy Museum, Chicago. On the first Friday of every month, the Adler hosts an evening of astronomy-related fun, including observing, lectures, planetarium shows, and tours of the facilities. For more information, call 312.922.7827; web site, www.adlerplanetarium.org.

AUGUST 17–21

Manitoulin Star Party

Gordon's Park, Manitoulin Island, Ontario. The site offers stargazing under the darkest skies in the region. In addition to the typical star-party fare, attendees will be treated to nature activities. For more information, visit www.gordonspark.com.

AUGUST 18–20

Connecticut River Valley Astronomers Conjunction

Northfield Mountain Recreation and Environmental Center, Northfield, Massachusetts. The weekend will feature talks by leading figures from the science and hobby of astronomy and a roundtable discussion. For more information, visit www.philharrington.net/astroconjunction.

AUGUST 18–20

Indiana Family Star Party

Camp Cullom, Frankfort, Indiana. This star party will feature sky tours, lectures, and activities for children. For more information, e-mail jmmahony@hotmail.com; web site, indianastars.us/starparty.

AUGUST 18–20

Northwoods Starfest

Hobbs Observatory, near Fall Creek, Wisconsin. Activities include speakers, presentations, a swap meet, door prizes, and deep-sky viewing. A 5-meter dish at the observatory will be of interest for fans of radio astronomy. For more information, call 715.877.1551; e-mail, nmoritz@centurytel.net; web site, www.cvastro.org.

AUGUST 19–20

Toledo Astronomical Association (TAA) Annual Star Party

Pioneer Boy Scout Reservation, Pioneer, Ohio. The TAA will showcase a number of large scopes during this weekend of camping and observing. For more information, visit www.toledoastronomy.org.

AUGUST 24–27

Saskatchewan Summer Star Party

Cypress Hills Interprovincial Park, near Maple Creek, Saskatchewan. The high-altitude park is now a dark-sky preserve, so terrific observing is guaranteed. For more information, visit www.usask.ca/psychology/sarty/rasc/starparty.html.

AUGUST 24–27

Starfest

The River Place, near Mount Forest, Ontario. The largest star party in Canada, this year's gathering will feature observing, workshops, and lectures by prominent astronomers. For more information, visit www.nyaa-starfest.com.

AUGUST 25–27

Black Forest Star Party

Cherry Springs State Park, near Galeton, Pennsylvania. Presented by the Central Pennsylvania Observers, this star party enjoys the darkest sky of the region. In addition to stargazing, the star party will feature numerous lectures. For more information, visit www.bfsp.org.

AUGUST 25–27

Sierra Summer Star Party

Martis Creek Park, near Truckee, California. After darkness falls, skygazers of any experience may tour the sky. At 10 P.M., nighttime activities will be dedicated to advanced observing. For more information, e-mail sssp@charter.net.

AUGUST 26

Lake Whitney Star Party

Lake Whitney Star Party, Whitney, Texas. The 1-day event will feature observing, lectures, and workshops. For more information, e-mail distglow2003@yahoo.com; web site, www.whitney-astro.com.

CONTACT INFORMATION

Please submit club announcements 5 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

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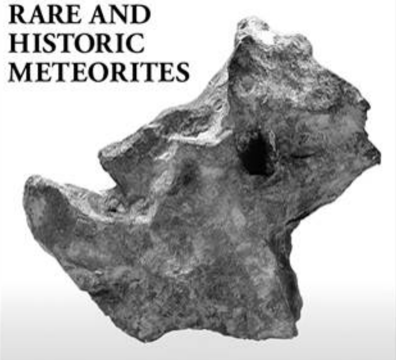

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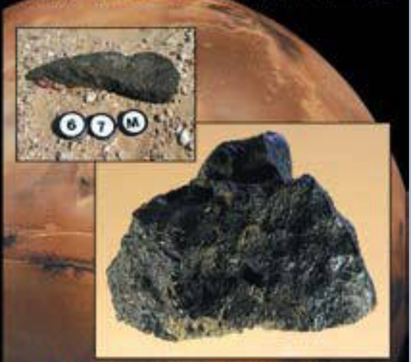

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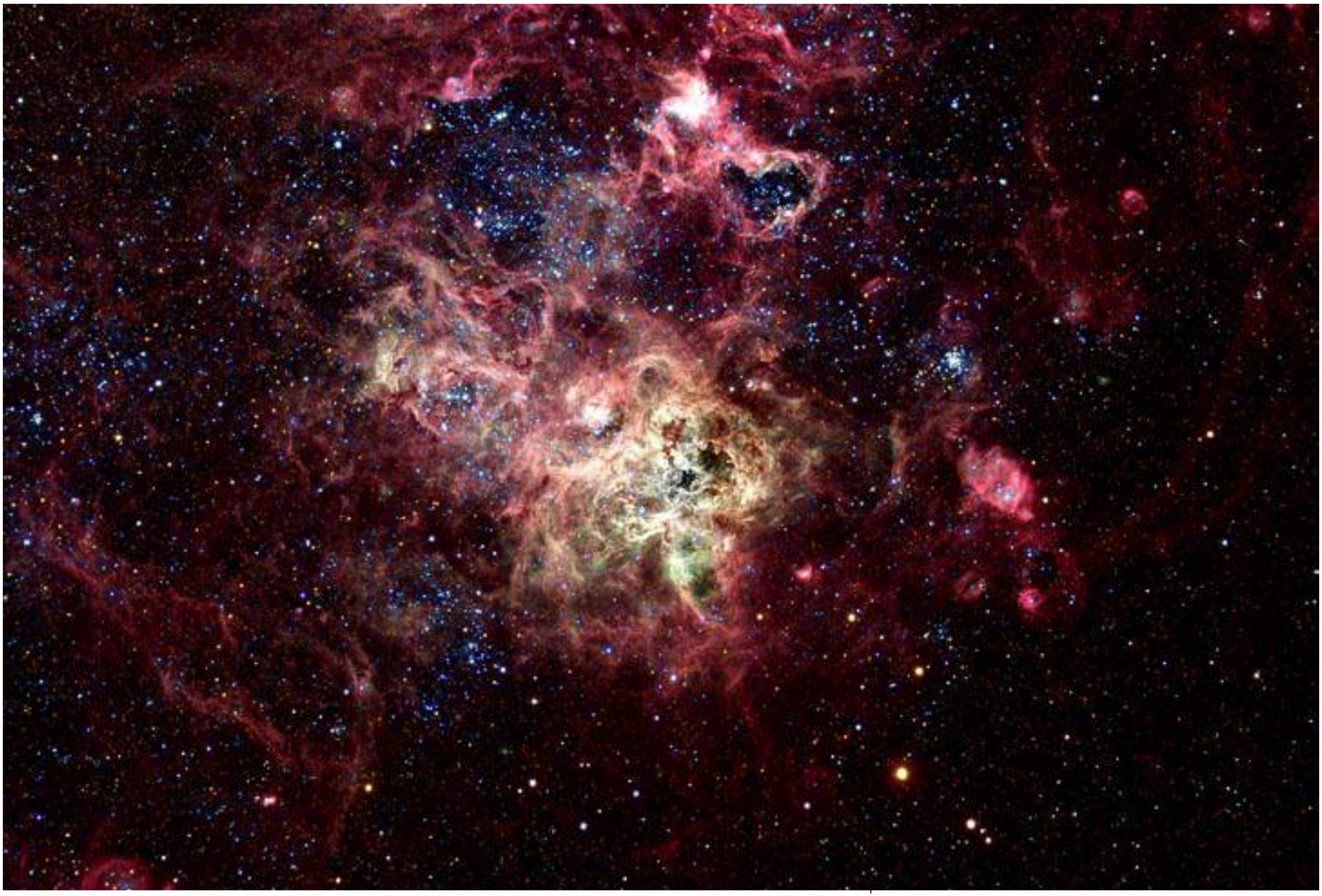
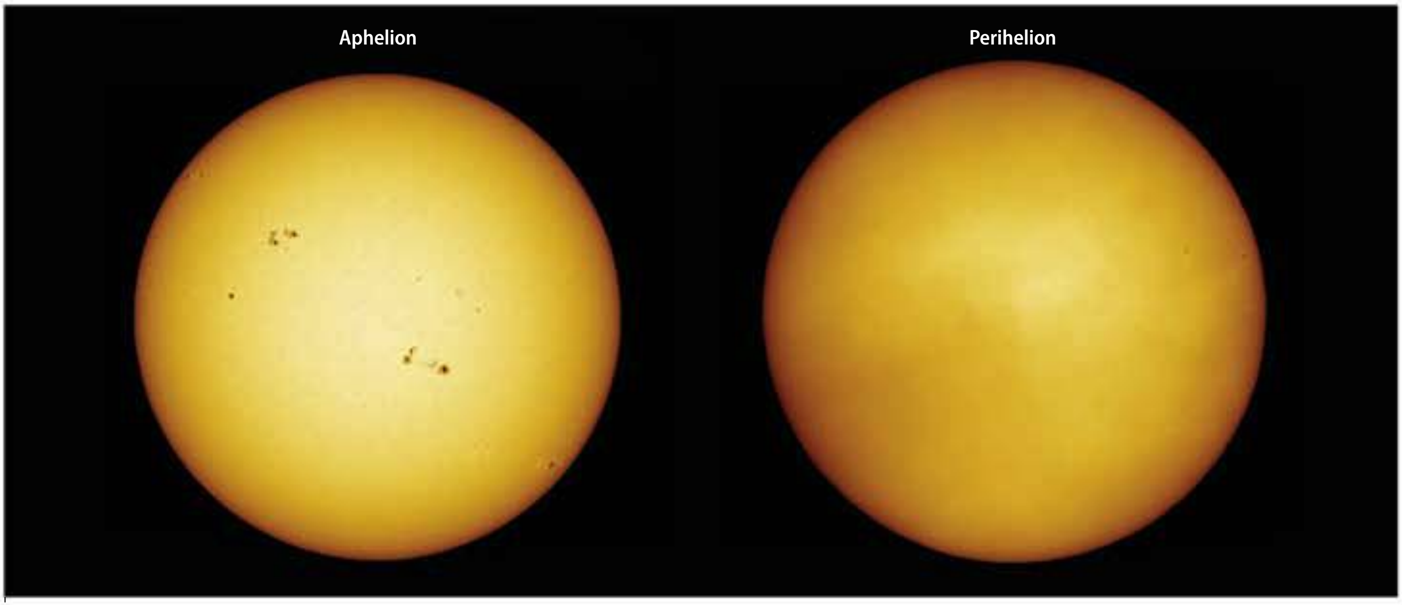


THE TARANTULA NEBULA (NGC 2070) (3.2-inch William Optics 80FD apochromatic refractor at f/5.6, SBIG 2000-XM CCD camera, HαRGB image with exposures of 14, 6.1, 5.3, and 5.8 hours, respectively, with 30-minute sub-exposures for Hα and 10-minute sub-exposures through the color filters. /// **BRAD MOORE, MELBOURNE, AUSTRALIA**

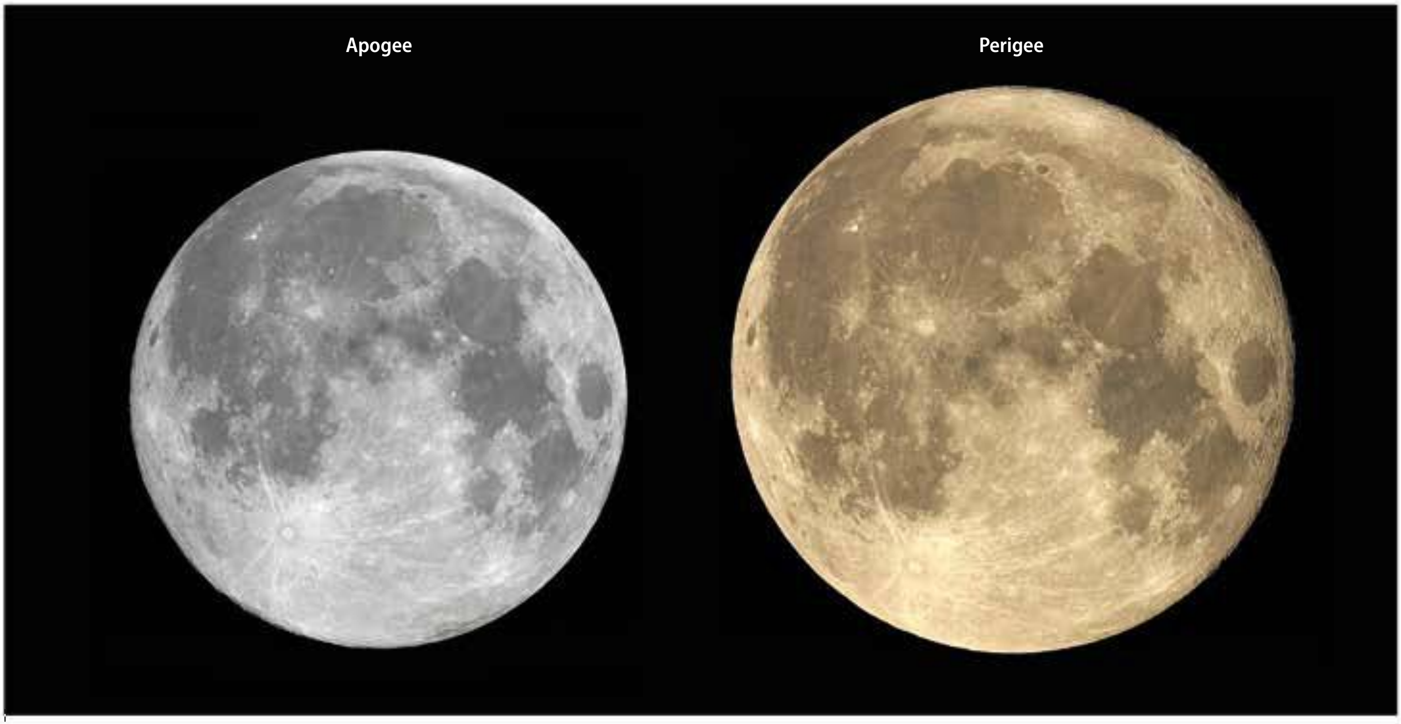
EXTRAGALACTIC ASTRONOMY

A nebula by any other name …

The Great Looped Nebula, more commonly known as the Tarantula Nebula (NGC 2070) lies in the Large Magellanic Cloud (LMC). The LMC, which lies in the southern constellation Dorado the Swordfish, is one of the Milky Way's satellite galaxies. The LMC lies approximately 170,000 light-years away. Originally cataloged as a star (30 Doradus), NGC 2070 shines at 8th magnitude and measures 40' by 25'. In the 19th century, most astronomers referred to NGC 2070 as the Great Looped Nebula, a name given to the object by English astronomer John Herschel (1792–1871). Today, we know NGC 2070 contains an intense region of star formation. If NGC 2070 were at the distance of the Orion Nebula (M42), it would fill nearly half the sky and cast a shadow.



APHELION AND PERIHELION denote times when Earth is farthest from and nearest to the Sun, respectively. Our planet travels around the Sun in a slightly stretched out orbit. As the size difference in these images show, Earth lies nearest to the Sun in early January (right) and farthest away in early July. Although the size difference is easy to see here, your eye won't detect it. (2.7-inch Tele Vue Pronto apochromatic refractor at f/6.8, Canon EOS 300D digital SLR, exposures of 1/800-second [left] and 1/2,500-second, ISO 100, taken July 5, 2005, at 10h09m24s UT [left] and January 4, 2005, at 10h53m52s UT) /// **ANTHONY AYIOMAMITIS, ATHENS, GREECE**



APOGEE AND PERIGEE describe points in the Moon's orbit when it lies farthest from and nearest to Earth, respectively. Unlike the small change in the Sun's diameter at its extremes, the Moon shows a 14-percent change in size between apogee and perigee. (2.7-inch Tele Vue Pronto refractor at f/6.8, Canon EOS 300D digital SLR, exposures of 1/3,200-second [left] and 1/800-second, ISO 800, taken February 13, 2006, at 22h32m UT [left] and July 21, 2005, at 23h05m28s UT) /// **ANTHONY AYIOMAMITIS, ATHENS, GREECE**

Send your photos to: *ASTRONOMY* Reader gallery, P. O. Box 1612, Waukesha, WI 53187; e-mail to readergallery@astronomy.com.
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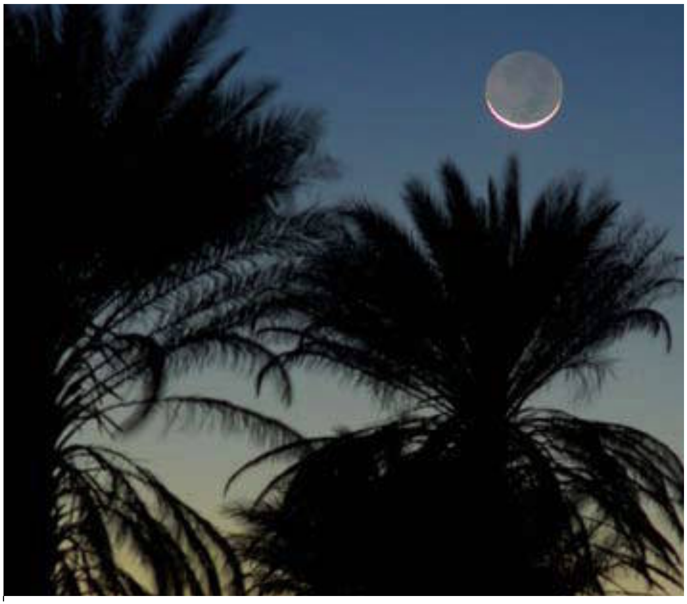
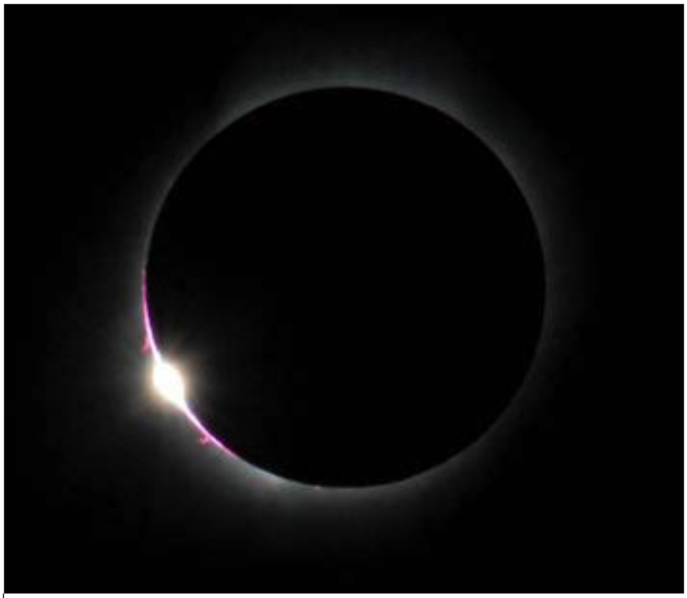
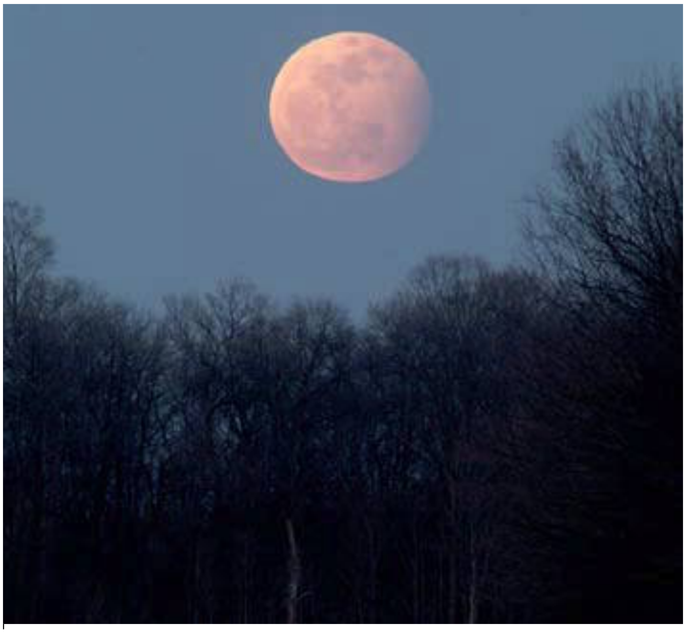


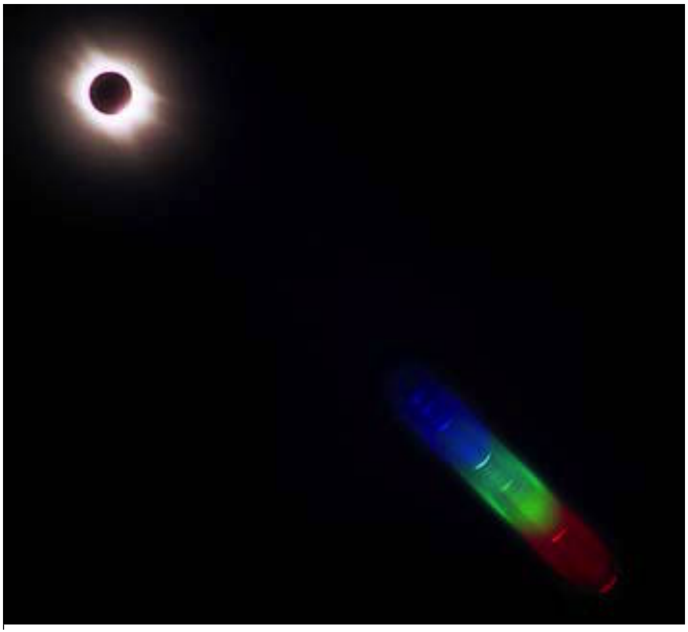
THE DAY AFTER the recent total solar eclipse, the Moon presented itself as a thin crescent. This image shows our only natural satellite a mere 30 hours and 40 minutes past New Moon. (Nikon D50 digital SLR, 180mm lens at f/5.6, ISO 400, 1⁄60-second exposure, taken March 30, 2006, at 16h56m UT near Timassah, Libya)
/// ENRICO MONTANARI, LUGO, ITALY



THE DIAMOND RING occurs in the moments just before and just after totality. Its appearances rank as the most dramatic events of any total solar eclipse. (Nikon D200 digital SLR, 400mm lens at f/40, ISO 640, 1⁄90-second exposure with a –4 f/stop exposure compensation, taken 9:14:32 A.M. local time from Tsiko, Togo)
/// JUDY BOWEN, ADETA, TOGO

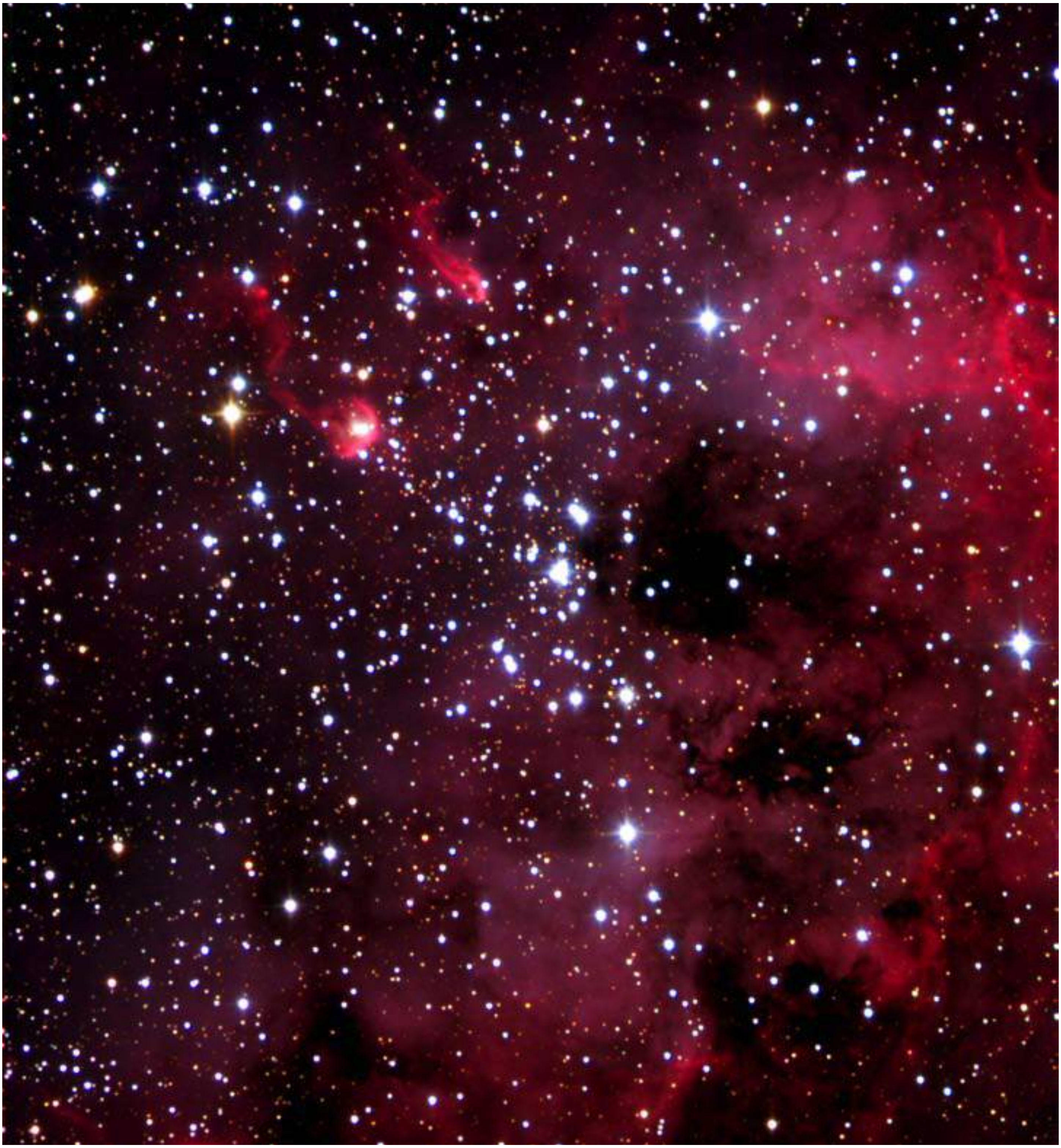


LUNAR ECLIPSES often occur 2 weeks before or after solar eclipses. On March 14, 2006, a penumbral lunar eclipse occurred — the Moon passed through only the lighter part of Earth's shadow, called the penumbra. (Fuji S-2 Pro digital SLR, Tamron SP 400/4 lens at f/11, ISO 400, 1⁄10-second exposure taken March 14, 2006, at 23h54m UT from LaOtto, Indiana)
/// ROBERT B. SLOBINS, FORT WAYNE, INDIANA



FLASH SPECTRA reveal the Sun's chemical composition. For a few fleeting seconds before and after totality, the solar chromosphere appears. Using a diffraction grating, imagers can capture the solar spectrum. (Canon AE-1 camera with motor drive, Tamron 80–200mm lens set at 150mm and f/4, Fuji 160S film, 1⁄60-second exposure, B & W transmission diffraction grating, taken from Colakli, Turkey) **/// ROBERT B. SLOBINS, FORT WAYNE, INDIANA**

EMISSION NEBULA IC 410 in Auriga lies 12,000 light-years away. The nebula surrounds open star cluster NGC 1893. Note the two "tadpoles" above and left of center. Their characteristic shape — with tails pointing away from NGC 1893's most energetic region — indicates the cluster's radiation sculpted the tadpoles out of the nebula's material. (18-inch Astro Works Centurion 18 at f/2.8, SBIG ST-2000 CCD camera, HαLRGB image with exposures of 135, 110, 30, 30, and 30 minutes, respectively) /// **DANIEL GOOD, MILLERSVILLE, PENNSYLVANIA**



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